LONG-TERM VEGETATION, CLIMATE, AND FIRE HISTORY

IN THE EASTERN UINTA MOUNTAINS,

UTAH, U.S.A.

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

A 2.13 meter-long sediment core from Reader Fen Basin (3205m asl) in the eastern Uinta Mountains provides a 10,250-year-long cal yr BP record of vegetation change and fire history. Few studies have explored the long-term vegetation and disturbance history from the Uinta Mountains. As a result, significant gaps remain in understanding historical processes affecting ecosystem dynamics from this region. The vegetation history at Reader Fen Basin suggests subalpine forest species (e.g., *Picea engelmannii* and *Pinus contorta*) expanded in the Uinta Mountains soon after glaciers retreated by 9000 cal yr BP. The charcoal-based fire history reconstruction from Reader Fen Basin suggests fires occurred on average every 470 years during the last 10,000 years. Three major shifts in vegetation composition occurred during the Holocene: 1) the displacement of grass and alpine herbaceous communities as arboreal species colonized the watershed, between 10,250 and 9000 cal yr BP, 2) the replacement of *Picea engelmannii* by the expansion of *Pinus contorta* forests into the watershed during the middle Holocene, beginning at 9000 cal yr BP when fire became more prominent in the ecosystem, and 3) a reduction of Cyperaceae as grasses began to dominate the fen during the last 3200 cal yr BP. These three major shifts in vegetation composition are largely the result of changing climate and fire frequency. Understanding the frequency and magnitude of past disturbances is necessary for understanding the catalyst of vegetation

change for making informed management decisions on present and future ecological change in the Uinta Mountains.

Dedicated to the dog and the boy.

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CHAPTER ONE

INTRODUCTION

Palynological investigations from radiocarbon-dated lake and wetland sediment sequences provide a window into the past by reconstructing vegetation patterns through the identification of pollen, spores, and plant macrofossils (Carrara et al., 1985; Faegri et al., 1989; Fall, 1997; Lowe & Walker, 1997). Reconstructing past changes in past vegetation in relation to disturbance regimes provides a framework for exploring climatic and ecologic fluctuations through time on local and regional scales (Fall, 1997; Ruddiman, 2008; Taylor et al., 2009).

Previous paleoecological research in the Uinta Mountains of Utah (Carrara et al., 1985; Munroe, 2003; Wright & Agee, 2004) hypothesized that fire is the dominant control of vegetation composition. I hypothesize that climate is the dominant driver of ecosystem dynamics in the high elevations of the Uinta Mountains. Species present in the harsh climatic conditions of the alpine-subalpine biome have adapted to thrive in niche environments, encouraging heightened sensitivity of these species to changes in climate. The high elevations of the Uinta Mountains present an ideal location for investigation of climate-vegetation interaction due to the minimal human influence to the area combined with the sensitivity of the alpine-subalpine biomes. Examining changes in floristic composition in relation to periods of past climate change will allow the dominant drivers of ecosystem change in the eastern Uinta Mountains to be evaluated. Finally, these findings will be compared with previous paleoecological investigations in adjacent mountain ranges of the western United States.

Climate controls the distribution of plants (Daubenmire, 1943). Prior paleoenvironmental work in northeastern Utah has suggested that millennial-scale changes in past moisture availability and mean annual temperature influence floristic communities at high-elevations (Munroe, 2003; Munroe et al., 2006). Large-scale controls of vegetation also include glacial influence associated with the development of Lake Bonneville and the subsequent downstream lake affect response on climate (Munroe et al., 2006). For example, during the past few centuries, variability and extent of snowpack in the Uinta Mountains is critical in monitoring the climate forcing agents, such as the influence of atmospheric circulation on moisture availability, that are present (Munroe et al., 2006).

Holocene fire and vegetation research in subalpine and boreal forests (e.g., Stocks et al., 1998; ACIA 2004; Calef et al., 2005; Flannigan et al., 2005; Girardin & Mudelsee, 2008) has suggested forests in both high-elevation and high-latitude settings are experiencing an increase in fire activity as fire season becomes longer due to seasonal changes in moisture availability. Previous work by Morris (2010) of regional fire regimes for south-central Utah suggests that high variability in fire return interval and magnitude results from climate drivers including El Nino/Southern Oscillation and the North American Monsoon. As vegetation communities change through time in response to climate, natural disturbance has been identified as a driver of forest composition and structure (Higuera et al., 2009). Fire events are considered significant when an episode consumes both understory and canopy vegetation, dramatically altering the landscape for a period of time (Thonicke et al., 2001; Wright & Agee, 2004; Agee & Skinner, 2005). Paleofire research suggests fire-driven disturbances are a necessary factor in maintaining a stable ecosystem and managing vegetative communities.

Objectives

Limited paleoecologic investigation in the high Uinta Mountains necessitates information on the historical processes affecting the biodiversity in this region. This study examines the importance of natural disturbance as a key ecosystem process through time. Quantifying the frequency of disturbance during the Holocene (defined in this paper as 11ka BP-present) provides a unique possibility to determine the resiliency of this system to natural and, more recently, anthropogenic change.

Understanding the frequency of past disturbances and the vegetation response in the Uinta Mountains provides a method for comparing this range to the long-term history of the Wasatch Mountains to the west and the Rocky Mountains to the east. This research provides the first >10,000-year long paleoenvironmental history from the Reader Fen Basin in the eastern Uinta Mountains and compares these findings to previous studies from the Intermountain West. Ecological processes within the Uinta Mountains are compared with other regional studies to determine local-versus-regional disturbance signals during the Holocene.

The study presented here explores the floristic history of Reader Fen Basin and identifies processes responsible for influencing long-term vegetation dynamics. The study also quantifies the frequency of disturbances and how they may shape the ecologic structure of high-elevation plant communities in the Uinta Mountains. I hypothesize that historically, climate has been the dominant driver of both vegetation composition and fire regimes in the eastern Uinta Mountains.

It has been hypothesized in this study that the floristic history of the eastern Uinta Mountains is controlled primarily by climate and the frequency and magnitude of past fire disturbance. Reader Fen Basin is ideally situated to answer this question due to the high-elevation and remoteness of the study site. Located at the forest-tundra boundary, vegetation at the Reader Fen Basin is expected to exhibit an increased sensitivity and corresponding response to climate variations. The remoteness of the site discourages the probability of human interaction with the area, though moderate accounts of land use are reported from employees of the Ashley National Forest.

During the twentieth century, land use and fire suppression have become increasingly important as a control of vegetation and fire. Historic activities in the Uinta Mountains, as reported by the Ashley National Forest, include timber harvesting near Chepeta Lake, approximately 3 km south of the Reader Fen Basin. These harvesting practices are generally minimal (<30 acres harvested) with pulses of increased acreage occurring at 1960 AD, 1973-1975 AD, and 1999 AD. These pulses range from 60-85 acres harvested. Timber harvesting in the area surrounding Chepeta Lake shows an increasing trend in the twentieth-century.

In an effort to determine the applicability of this hypothesis on the Reader Fen Basin study site, four studies reconstructing late Quaternary glaciation and vegetation change for high-elevation locations surrounding the study site were considered, including studies by Carrara et al. (1985), Madsen and Currey (1979), Louderback and Rhode (2009), and Jimenez-Moreno et al. (2007) (Table 1).

Carrara et al. (1985) offer insights into the vegetation response of the high elevations located near the northeastern slope of the Uinta Mountains at Leidy Peak. Leidy Peak is located approximately 20 km north of Reader Fen Basin at an elevation of 3135 meters. Vegetation at the site is primarily wetland, dominated by Poaceae and Cyperaceae, with surrounding subalpine forest, dominated by *Picea engelmannii*, *Abies lasiocarpa*, and *Pinus contorta*. Re-evaluation of the Carrara et al. (1985) study allows for insight into the climatic transitions reflected through pollen analysis for both the northern and southern slopes in the eastern Uinta Mountains.

Madsen and Currey (1979) investigated late Quaternary glacial and vegetation patterns in the area of Snowbird bog (actually a fen) in the Wasatch Mountains, Utah, located roughly 300 km south-southwest of the Reader Fen Basin (Figure 1). Their study explores shifts in Holocene climate based on observed changes to vegetation from the pollen record. These vegetation shifts are believed to be the result of variations in summer temperature, which controls the upper limit of conifer forest species composition and distribution (Daubenmire, 1954; Madsen & Currey, 1979).

At the Snowbird bog, Little Cottonwood Canyon site, Madsen and Currey (1979) identify Hudsonian and Alpine vegetation communities (Merriam, 1898) in the modern high-elevation communities, above 3200 m, roughly the same elevation as the modern Reader Fen Basin. The authors compare changes in the concentration of subalpine conifer forest species, *Picea engelmannii*, *Pinus flexilis*, and *Abies lasiocarpa*, with sagebrush (*Artemisia* and Chenopodiaceae-Amaranthaceae) and alpine meadow

Table 1: Regional Analysis Modern Climate Data

Site	Latitude Longitude	Elevation (meters)	Summer Temperature Average	Winter Temperature Average	Summer Precipitation Average	Winter Precipitation Average	Modern Vegetation	Weather Station	Reference
Reader Fen Basin	40.770 N, -110.041 W	3300	9.49	-8.86	60.36	21.16	wet meadow, alpine meadow, subalpine forest	Chepeta Lake	This study
Leidy Peak	40.460 N, 109.501 W	3135	11.42	-7.72	53.95	18.47	wet meadow, subalpine forest	Trout Creek	Carrara et al. (1985)
Snowbird bog	40.664 N, 111.650 W	2470	13.59	-4.98	126.58	52.45	fir forest	Snowbird	Madsen and Currey (1979)
Blue Lake Marsh	40.500 N, 114.036 W	1296	24.35	-1.18	0.95	0.69	Cyperaceae, *Potamogeton*, Poaceae wetland	Wendover Airport WSO	Louderback and Rhode (2009)
Bear Lake	41.951 N, 111.308 W	1805	18.24	-4.06	2.00	3.64	*Artemisia* steppe, fir forest	Bear Lake State Park	Jimenez-Moreno, et al. (2007)

Location and modern climate data for studies conducted at Snowbird bog (Madsen & Currey, 1979), Blue Lake (Louderback & Rhode, 2009), and Bear Lake (Jimenez-Moreno et al., 2007). Climate data for Reader Fen Basin, Leidy Peak, and Snowbird bog were obtained from National Water and Climate Center: SNOTEL (www.wcc.nrcs.usda.gov/snow/). Data for Blue Lake Marsh and Bear Lake were obtained from the Western Regional Climate Center (www.wrcc.dri.edu/). Studies used in analysis of Reader Fen Basin, Uinta Mountains.

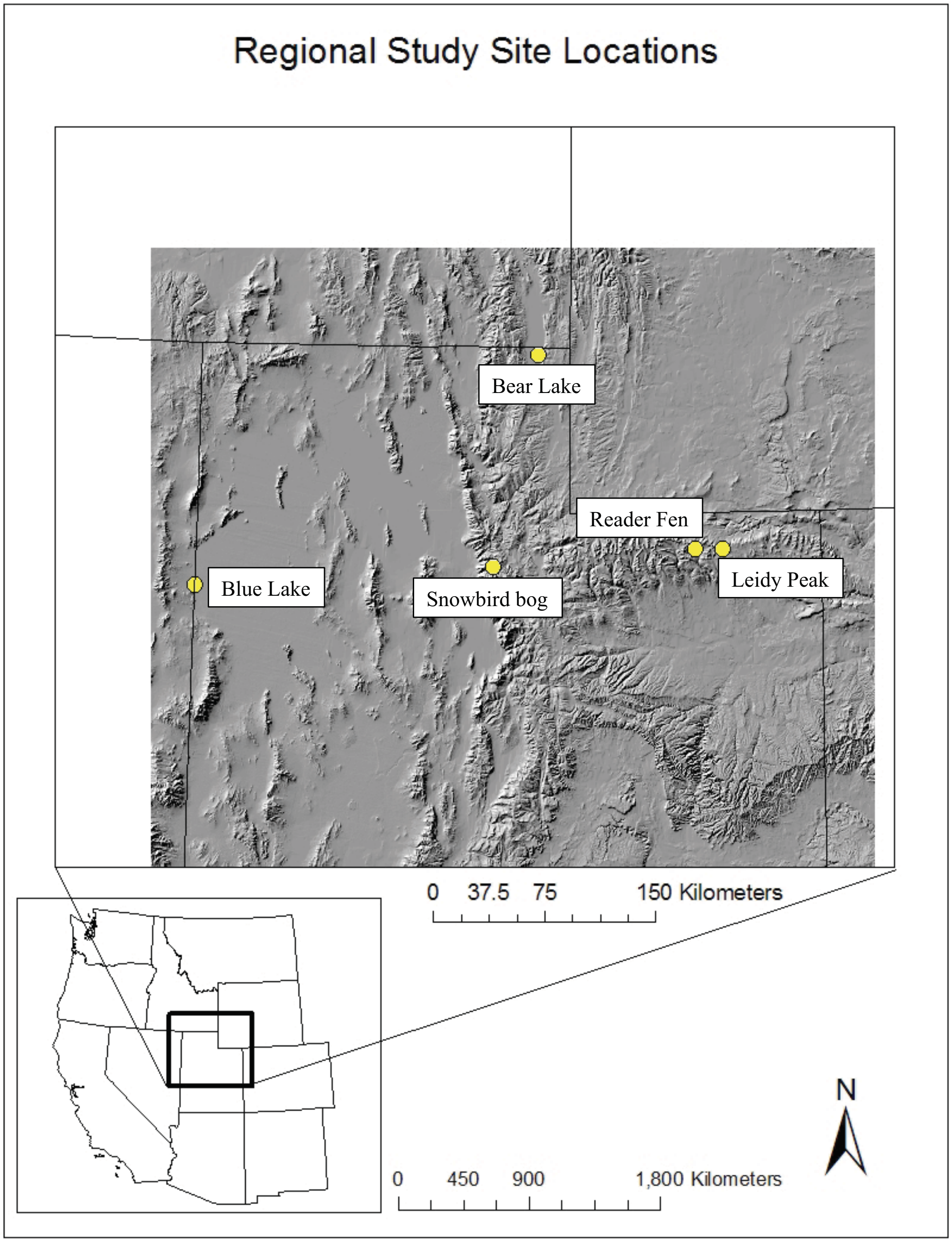

Figure 1: Regional Study Site Locations. Location of study sites Reader Fen Basin, Leidy Peak (Carrara et al., 1985), Snowbird bog (Madsen & Currey, 1979), Blue Lake Marsh (Louderback & Rhode, 2009), and Bear Lake (Jimenez-Moreno et al., 2007). DEM image created from Utah Automated Reference Center.

(Asteraceae, Poaceae, *Plantago*, and *Ribes*) as evidence of Holocene climate change. Madsen and Currey (1979) suggest open sagebrush and alpine meadow communities converted into conifer forest as summer temperature increased during the mid-early Holocene.

The Snowbird bog core also contains evidence of multiple glacial till deposits, indicating repeated glacial advances on the western base of the Wasatch Mountains (Madsen & Currey, 1979). Deglaciation began approximately 13,000 cal yr BP (calendar years before present, present=1950) as alpine vegetation colonized the area (Madsen & Currey, 1979).

The Blue Lake study, located approximately 480 km west of the Reader Fen Basin and located at lower elevation, 1297 m (Figure 1), is a spring-fed marsh currently dominated by *Schoenoplectus*, *Carex*, and *Salix* along open streams and *Distichlis* and *Suaeda* in the drier meadow areas (Louderback & Rhode, 2009). This study examines decadal to millennial-scale climate forcing in the low-elevation wetland by using pollen analysis to explain the last 15,000 cal yr BP.

At Blue Lake, centennial-scale climate shifted between warmer- and cooler-than-present conditions as wetlands gave way to grass meadows, marshlands, and playa communities, resulting from Holocene climate fluctuations; the authors concluded cooler-than-present periods occurring between 4.4-3.4 ka cal yr BP and 2.7-1.5 ka cal yr BP and warming between 3.4-2.7 ka cal yr BP and from 1.5 ka cal yr BP to present. Similar to the results of Madsen and Currey (1979), at higher elevation, climate fluctuations at Blue Lake coincide with migrations of dominant grassland and playa species in and out of the system.

The Bear Lake study site, located approximately 150 km north-northwest of the Reader Fen Basin study site at elevation 1805 m, collects runoff from the nearby Bear River. During periods of high precipitation and cold temperatures, the Bear River runs through the southern and eastern flanks of the high elevation Uinta Mountains (Jimenez-Moreno et al., 2007). During periods of cold, wet conditions, when glaciers were at their maximum extent for the region, high-elevation pollen types increased in Bear Lake, including cold-tolerant species from the Uinta Mountain. During interglacial periods, Bear Lake became a closed basin supporting vegetation favoring warm, dry conditions, similar to modern conditions. Bear Lake is characterized today as having high concentrations of *Artemisia* steppe, *Pinus edulis*, and *Juniperus osteosperma* pollen, comparable to the mid-lower elevations of the Uinta Mountains.

Jimenez-Moreno et al. (2007) report on a 225 ka cal yr BP high-resolution pollen record from Bear Lake, Utah-Idaho, to investigate the regional response of vegetation to orbital and millennial-scale climate change. The study suggests, similar to the Louderback and Rhode (2009) Blue Lake study, vegetation has responded on millennial time scales to climate forcing (Jimenez-Moreno et al., 2007). For example, abrupt changes in vegetation communities coincide with millennial-scale Heinrich events, most apparent during H4-H6 (H4=38 kyr, H5=46 kyr, H6=60 kyr), when warm, arid vegetation (*Ambrosia*, Chenopodiaceae-Amaranthaceae, *Sarcobatus*, *Juniperus*) was replaced by cool, wet vegetation (*Picea*, Asteraceae).

Modern biogeography in the Uinta Mountains is characterized by several distinct mountain vegetation zones that are common across the intermountain region; however, unlike the rest of the Middle Rocky Mountains, including the nearby Wasatch Mountains, the Uinta Mountains have few endemic species (Shaw & Long, 2007). Regional analysis of the studies by Carrara et al. (1985), Madsen and Currey (1979), Louderback and Rhode (2009), and Jimenez-Moreno et al. (2007) provide the insight necessary for understanding regional response of vegetation to climate disturbance.

CHAPTER TWO

THE SETTING

Uinta Mountains

Considered one of the smaller area ranges of the Middle Rocky Mountains, the Uinta Mountains distinguish themselves with several unique characteristics: the most notable being the east – west geographic orientation. The Uinta Mountains are situated between the Wasatch Mountains of northeastern Utah and the central portion of the Rocky Mountain Range. The range is bordered north and south by the Green River Basin and the Uinta Basin, respectively. The Uinta Mountains measure approximately 150 km long by 38 km at the widest point with an elevation of 1800-3900 m. The Uinta Mountains are also distinctive for their floristic communities spread across an elevation gradient of diverse habitats. The lower communities of Pinyon-Juniper (*Pinus edulis*-*Juniperus*) at approximately 2000 m elevation, are followed by regions of Ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), and Lodgepole pine (*Pinus contorta*) as you increase elevation to the subalpine fir and tundra zones extending to the highest elevations, at over 4000 m at the summit of Kings Peak (Shaw & Long, 2007).

These distinctive characteristics, combined with a limited history of paleoenvironmental research from the high Uinta Mountains have prevented a framework for understanding the linkages among long-term climate variability, natural disturbance, and vegetation history of the mountain range.

Geology

Sedimentary rocks of the Uinta Mountain Group, deposited during the Neoproterozic (770-740 Ma) make up the core and majority of the Uinta Mountains (Dehler & Sprinkel, 2005), with quartzite-rich and arkosic sandstone of the Hades Pass formation underlying the Reader Fen Basin. The durability of these semi-metamorphosed rocks is thought to be responsible for the stability of this mountain range during glacial periods, when most high-elevation geomorphic features were formed (Atwood, 1907; Hayward, 1952; Ostler, Harper, McKnight, & Anderson, 1982). Major structural features include the anticline of the Uinta Mountain crest and three major faults, North Flank Fault, Henrys Fault, and Uinta Fault, with the Uinta Fault holding dominance (Hansen, 1975). Uplift along these faults during the Laramide Orogeny (70-35 Ma) began the geologic and geomorphic development of the Uinta Mountains (Bockheim & Koerner, 1997).

During the Last Glacial Maximum, approximately 21,000 years ago, ice was thought to have covered the majority of the Uinta Mountains above 3048 m, stretching 132 km east west and 68 km north south (Atwood, 1907; Munroe et al., 2006). Reader Fen Basin is thought to be a glacially formed trough, now occupied by a meadow complex, which was created behind recessional moraines deposited during deglaciation (Ostler et al., 1982).

Climate

Whitlock and Bartlein (1993) compiled an analysis of climatic change for the Western USA, concluding that climate of the Uinta Mountains fluctuates between two types of seasonal precipitation regimes: winter wet/summer dry and winter dry/summer wet. In a winter wet/summer dry regime, orographic precipitation arrives as storm tracks move into the region, following the jet stream as it travels across the northern Pacific Ocean (Whitlock & Bartlein, 1993; Munroe, 2003; Shaw & Long, 2007). In a winter dry/summer wet regime, precipitation is controlled by a monsoonal pattern resulting from moisture moving northwards from the Gulf of Mexico (Whitlock & Bartlein, 1993; Munroe, 2003; Shaw & Long, 2007). Modern climate at Reader Fen Basin, Uinta Mountains, Utah, is primarily dominated by a winter dry/summer wet regime, shown in Figure 2 and Figure 3.

Modern climate at Reader Fen Basin is characterized by 5.84 cm of precipitation in summer (defined as June/July/August) versus 5.59 cm of precipitation in winter (defined as December/January/February). High and low temperatures range from 7.19°C to 11.38°C in summer and -9.24°C to -5.48°C in winter (Figure 2).

Fen Systems

A fen is peat-accumulating wetland, generally with a circum-neutral pH, which is fed by runoff or drainage from surrounding areas (Mitsch & Gosselink, 1993). A peat-accumulating fen system is recharged primarily by groundwater flow encouraging the collection of dissolved minerals acquired during the flow through the surrounding regolith (Bedford & Godwin, 2003). This water system allows the fen to be nutrient rich

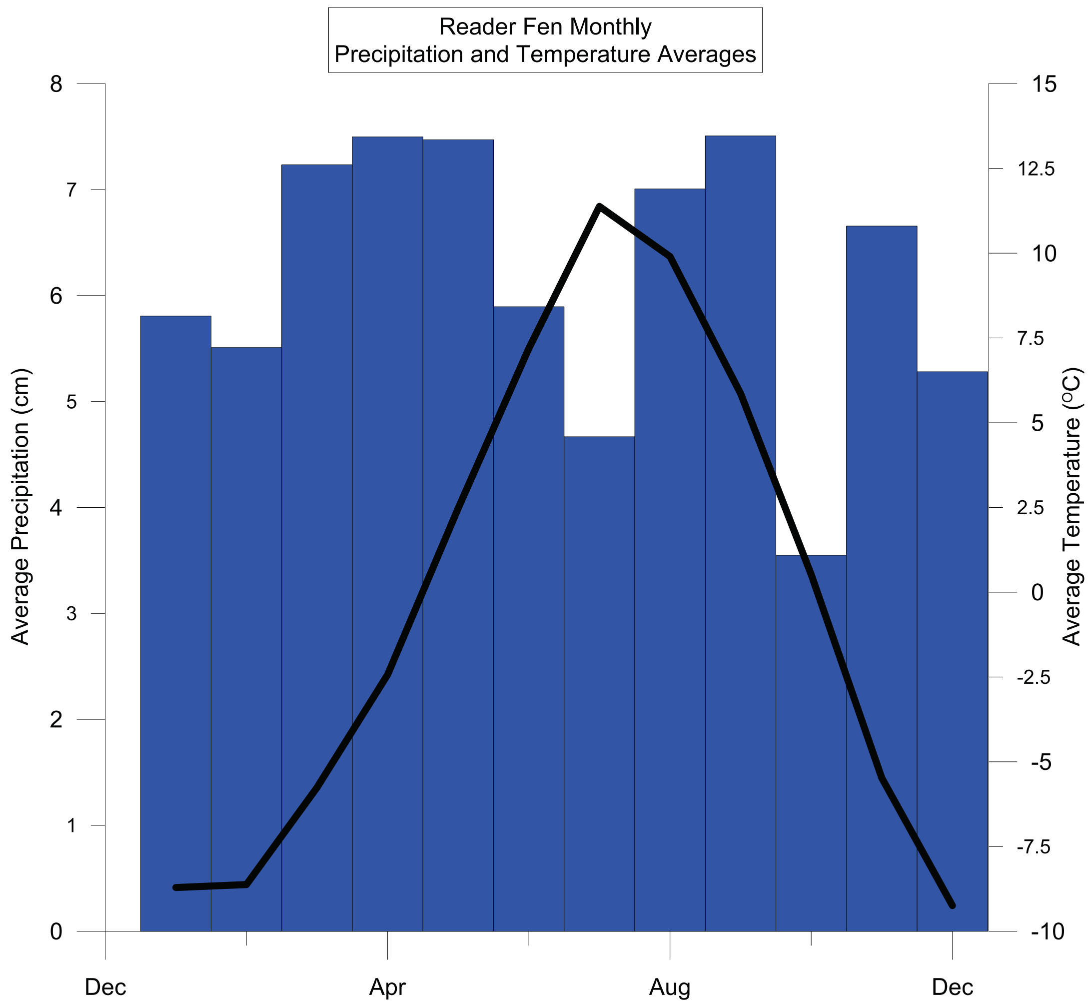

Figure 2: Reader Fen Monthly Precipitation and Temperature Averages. Climograph shows data for Chepeta, UT (40°46' N, 110°1' W, elevation 3228 m). Graph was completed using SNOTEL data from the Natural Resources Conservation Service. Precipitation is indicated by the blue histogram and spans 1982-2010; Temperature is indicated by the solid black line and spans 1990-2010.

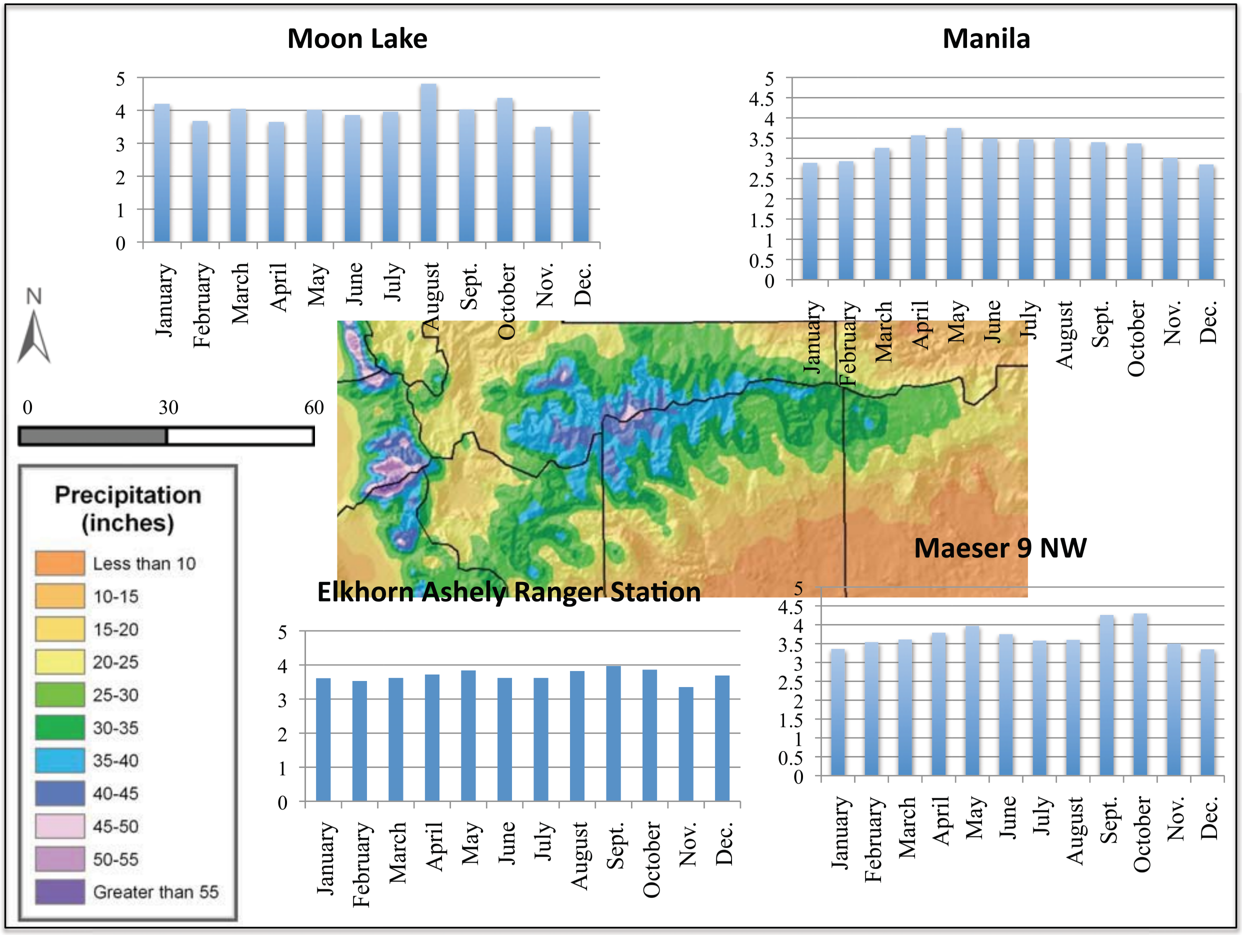

Figure 3: Modern Climate Summary for Eastern Uinta Mountains, UT. Records for Elkhorn Ashley Ranger Station: 1910-1956, Maeser 9 NW: 1983-2009, Manila: 1910-2009, Moon Lake: 1935-1969 from the Western Regional Climate Center (www.wrcc.dri.edu/Climsum.html). Map image from PRISM Climate Group, Oregon State University (www.prism.oregonstate.edu).

and capable of supporting marsh-like vegetation, including *Carex*. Bogs, which are recharged primarily through precipitation creating acidic and low nutrient conditions, are uncommon in the Intermountain West, specifically the Wasatch and Uinta Mountains ranges, due to low amounts of summer precipitation (Cooper & Andrus, 1994). Having a steady supply of water, a fen system is able to create a stable, anaerobic environment ideal for the accumulation of peat and the preservation of plant and pollen material (Charman, 2002).

Similar to densely vegetated forest regions, peat-accumulating wetlands (peatlands) provide a sink for carbon sequestering. A study done by Yu et al. (2010) states that peatlands comprise roughly 3% of the global land area with the majority of peatlands originating during the Holocene. Patterned fens, such as that found at the Reader Fen Basin study site, are one of the primary wetland types found in boreal and subarctic regions located north of 45°N (Yu et al., 2001; Ford et al., 2006). However, Ford et al. (2006) and Matyjaski et al. (2003) note the occurrence of Reader Fen Basin at approximately 40.77°N latitude may occur near the southern limit for patterned fens in North America.

Reader Fen Basin Study Site

The Reader Fen Basin watershed (Figure 4) is comprised of upper, middle, and lower meadow areas occupied by patterned valley fens retained by glacial till at their lower ends. Previous work in the Reader Lakes, UT area by Matyjaski et al. (2003) and Ford et al. (2006), using the hydromorphological classification defined by Charman (2002), has shown the Reader Fen Basin to contain areas of basin/depression fen, sloping

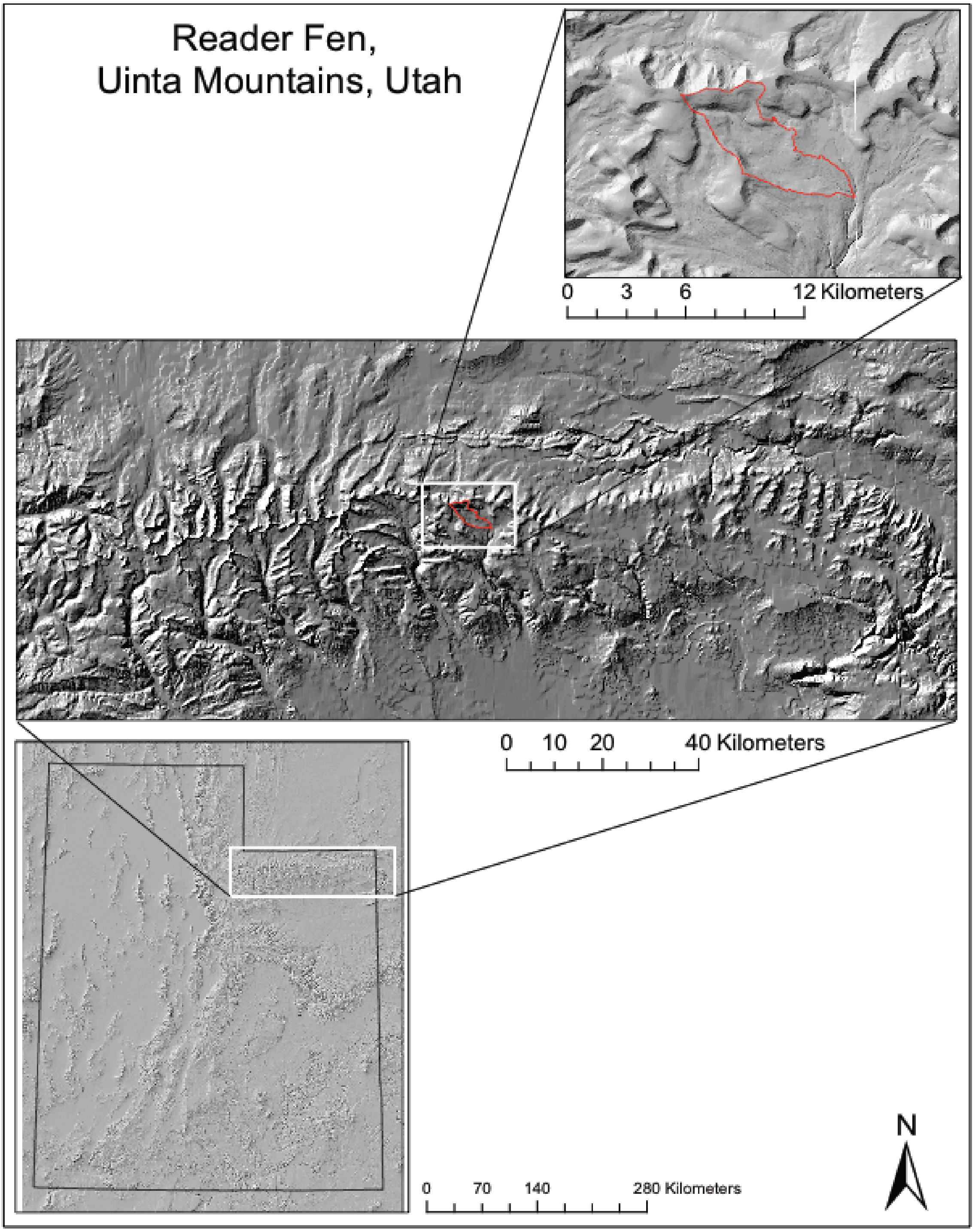

Figure 4: The Study Site. Reader Fen Basin watershed (red outline) is located on the Southeast slope of the Uinta Mountain Range in Northeastern Utah in Northern Duchesne County (40.770462, -110.040863). Approximately 55 km northwest of Whiterocks, Utah, Reader Fen Basin is within the Ashley National Forest (Hansen, 1975). Reader Fen Basin is found near Marsh Peak, which is one of four defining peaks of the Uinta Mountains as described by a U. S. Geological Survey of the region (Atwood, 1907). DEM image created from Utah Automated Reference Center.

fen, valley fen, and floodplain fen. This study focuses on a sediment core (RF10C2) collected from a valley fen area, which exhibits a string and flark pattern, or sloping patterned fen. The string and flark pattern results from areas of ridge-and-pool morphology mottling the valley fen (Figure 5). In this classic fen pattern, the string sections are composed of raised, hummocky ridges, while the flarks are sunken pockets, often inundated with water. Matyjaski et al. (2003) states the accumulation in the Reader Fen Basin ranges from approximately 1 m in sloped regions to 2 m or more in valley settings.

Wetland hydrology and groundwater chemistry research conducted by Ford et al. (2006) states that a sloping fen within the Reader Fen Basin is recharged primarily by groundwater from springs located along the southern and western boundaries of the fen. Geochemical data from Ford et al. (2006) indicates a circum-neutral pH for the Reader Fen Basin, resulting from the shallow groundwater system that feeds the site.

Local Vegetation

The Reader Fen Basin study area is at approximately 3300 m elevation, and extends from lodgepole pine (*Pinus contorta*) and spruce forest (*Picea engelmannii*) to tree line on the eastern end of the range. A botanical survey of Reader Fen Basin concludes the area contains modern vegetation communities of wet meadow and riparian species, subalpine forest species, and upland species (alpine meadow). Open, wet meadow genera include: *Carex*, *Eriophorum*, *Trichophorum, Pedicularis, Caltha, Dodecatheon, Danthonia,* and *Deschampsia*. Riparian species include: *Salix*, *Gentiana*, *Potentilla, Betula,* and *Rhodiola* Subalpine forest species include: *Pinus contorta, Picea*

Figure 5: Reader Fen Basin Site Photograph. Photograph shows the characteristic string and flark pattern of the fen, as well as the relationship of the fen to subalpine forest location.

engelmannii and *Abies lasiocarpa*. Upland species include: *Solidago, Antennaria,* and *Achillea*.

Regional Vegetation

Modern vegetation of the Wasatch Mountains has several key differences from the Uinta Mountains. Vegetation found at Snowbird bog (Madsen & Currey, 1979) includes areas of *Pseudotsuga menziesii* and *Populus*, *Salix* and *Alnus*, and *Picea engelmannii* and *Abies lasiocarpa*. Modern Blue Lake Marsh (Louderback & Rhode, 2009) is comprised primarily of wetland taxa (Cyperaceae, *Potamogeton*, Poaceae) with terrestrial pollen dominated by *Pinus*, *Juniperus*, and Chenopodiaceae-Amaranthaceae. The study by Jimenez-Moreno et al. (2007) conducted at Bear Lake is comprised of diverse regions of *Artemisia* steppe, *Pinus edulis* and *Juniperus* dominant forest, *Populus tremuloides* forest, and *Picea engelmannii* and *Abies lasiocarpa* dominant forest surrounding the basin. Despite local-scale differences in vegetation composition, the regional flora of the Intermountain West can be characterized by four major plant zones following the work of C. Hart Merriam (1898). These zones include: transition (1828-2540 m), Canadian (2438-2895 m), Hudsonian (2895-3500 m), and alpine (3400-3657 m).

CHAPTER THREE

METHODS

Field Methods: Livingstone Core

A composite 2.13-m-long sedimentary core was obtained for this study from Reader Fen Basin in September of 2009. Six additional composite cores from adjacent areas within the fen were obtained in July of 2010 using a Livingstone corer. Cores were collected at several locations across the fen to identify the best location for producing a complete Holocene record of vegetation, disturbance, and climate variability. Ultimately, core RF10C2 was used for this analysis and was located approximately 10 m west of Reader Creek, collected along a string.

Laboratory Methods

The 2.13-m Livingstone long core (RF10C2) was transported to the Garrett Herbarium at the University of Utah, where it was stored in refrigeration to be analyzed to determine the vegetation and fire history for the Reader Fen Basin site. The 6-cm-diameter core segments were sectioned into two halves, with one half preserved and one half used for subsampling. The core was sampled at 4 cm intervals for the top 1.01 m and at 8-cm intervals for the remaining to extract fossil pollen. The core was also sampled at 1 cm intervals for charcoal (approximately every 40 years). Macrofossils were recorded as they appear with the pollen and charcoal samples.

Chronology

Six sediment samples from the composite core were submitted for radiometric dating to Beta Analytic. The Accelerated Mass Spectrometry have been analyzed and provided basal ages of 8810 +/- 50. The radiocarbon results were calibrated to calendar years BP using CALIB Radiocarbon Conversion Version 6.0.1 (Reimer et al., 2010) (Table 2). A best-fit age model was generated to allow interpretation of pollen assemblage and charcoal analysis data to be possible on a more relevant scale (Figure 6).

Sedimentation rates in fens are believed to be controlled largely by climatic conditions, fen morphology, and regional vegetation composition (Futyma & Miller, 2001; Miner & Ketterling, 2003; Gasiorowski, 2008). Gasiorowski (2008) states that meadow areas characterized by dense vegetation, such as the Reader Fen Basin site, aid in minimizing sediment disruption by fauna or hydrologic circulation patterns for the location. Based on this theory, the Reader Fen Basin study site is believed to maintain stable deposition that may be punctuated with rapid deposition of coarse sand layers from seasonal precipitation and snowmelt events.

The best-fit age model considers radiometric results, changes in lithology, and magnetic susceptibility. Periods of rapid sedimentation resulting from flood events are believed to occur at depths of approximately 0.46-0.54 m and 1.33-1.34 m (Figure 7).

Table 2: Radiocarbon Data Summary

Original Depth (meters)	Corrected Depth (meters)	Sample Number	Sample Material	^{14}C Age Cal yr BP	CALIB 6.0.1 Calibrated Age Cal yr BP
0.53-0.54	0.47-0.48	RF10 C2D2 53-54	Sandy Silt Clay	2250 +/- 30	2156-2266
0.72-0.73	0.66-0.67	RF10 C2D3 72-73	Silty Clay	2400 +/- 40	2342-2514
1.02-1.03	0.96-0.97*	RF10 C2D3 102-103	Sandy Silt Clay	2110 +/- 40	1987-2158
1.5-1.51	1.44-1.45	RF10 C2D4-150-151	Silty Clay	5570 +/- 40	6291-6413
1.85-1.86	1.79-1.80	RF10 C2D5-185-186	Silty Clay	7670 +/- 40	8399-8543
2.05-2.06	1.99-2.0	RF10 C2D5-205-206	Peat	8810 +/- 50	9670-9966

Report of radiocarbon dating analyses from Beta Analytic Inc. Results are reported in radiocarbon years before present (present = 1950) and were calibrated into calendar years before present using CALIB Radiocarbon Conversion Version 6.0.1 (Reimer et al., 2010). Samples RF10 C2D3 72-73, RF10 C2D4-150-151, RF10 C2D5-185-186, and RF10 C2D5-205-206 were processed September 9, 2010. Samples RF10 C2D2 53-54 and RF10 C2D3 102-103 were processed March 28, 2011. *Sample RF10 C2D3 102-103 was eliminated from the best-fit age model because of believed contamination resulting from the sand layer (depth 0.46-0.54) allowing groundwater to flow freely through the sediment matrix and causing contamination by younger carbon.

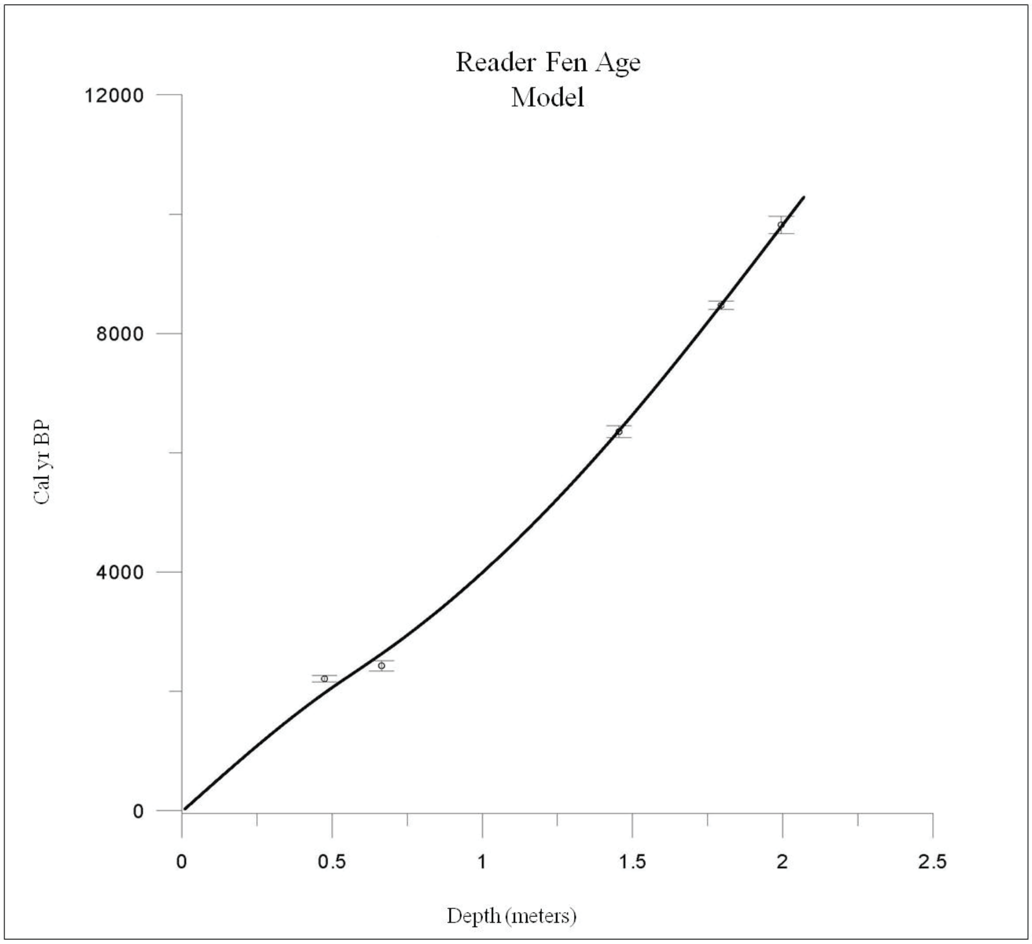

Figure 6: Reader Fen Depth-Age Model. Model generated using CALIB Radiocarbon Conversion Version 6.0.1 (Reimer et al., 2010). Based on proposed sedimentation rates for the Reader Fen Basin study site, smoothing spline (x=age ~ depth) was created with the output values spar = 0.3 and lambda = 0.000664071. Equivalent degrees of freedom = 4.176971.

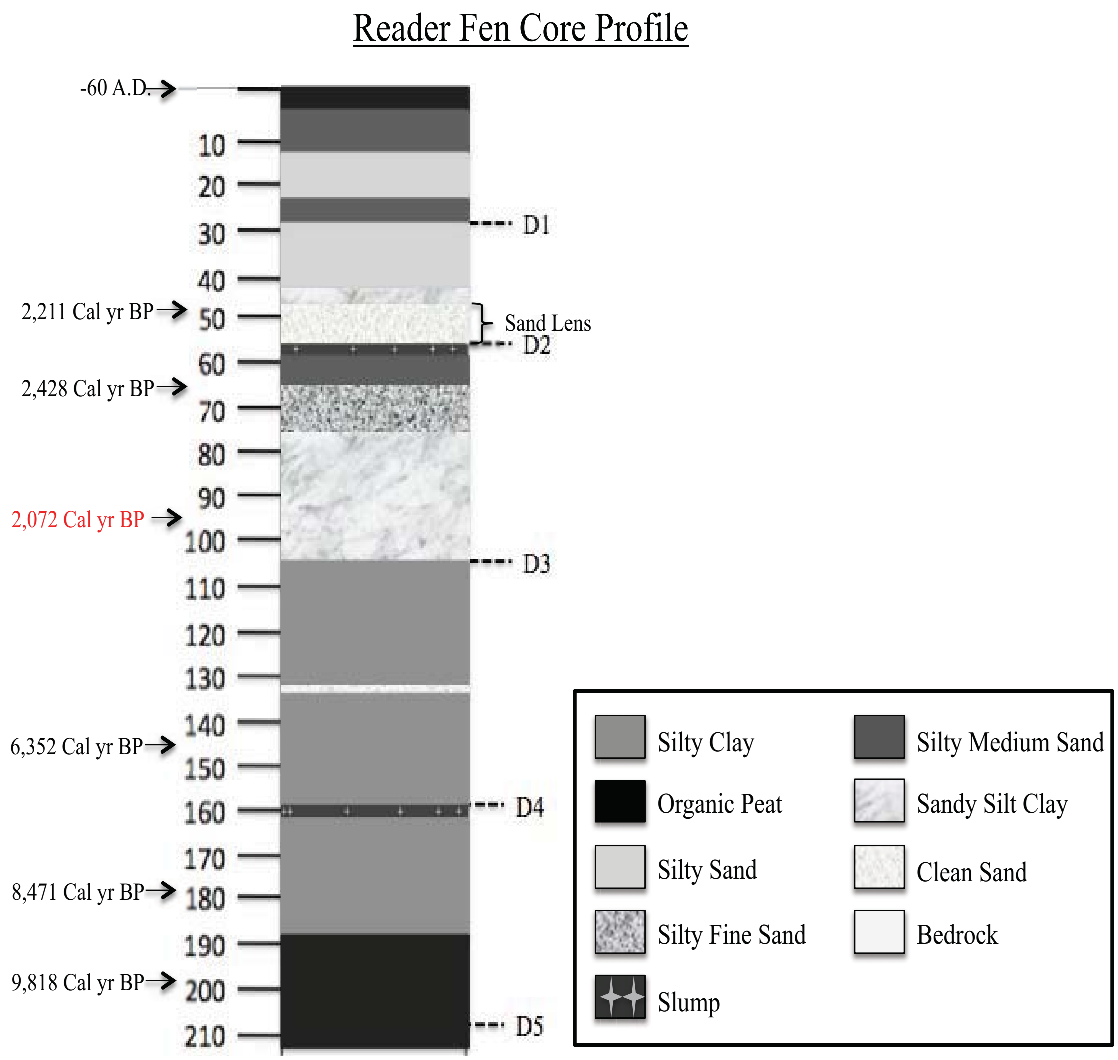

Figure 7: Core Profile for Reader Fen 2010 Core 2. D1-D5 indicates core segments obtained through successive drives.

The sand lens occurring from 0.46-0.54 m is assumed to have accumulated rapidly as the result of a flood event; to accommodate this period of accelerated deposition, a master core depth was created to reflect the long-term sediment accumulation rate. The sand lens deposit (original depth 0.46-0.54 m) was subtracted from the age-depth calculation, as it was assumed to be an instantaneous event; this resulted in a 0.06 m decrease in original depth, 2.13 m, to the corrected depth 2.07 m. Depths at which radiocarbon dates were obtained were adjusted following the corrected depth for use in creating the best-fit age model (Table 2).

Sample RF10 C2D3 102-103 was not included in the best-fit age model as the radiometric date was believed to be too young due to contamination by younger carbon, resulting in a date reversal. The cause of contamination is thought to be the result of younger organic material and sediment leaching through the sediment matrix following intense flooding events beginning approximately 2000 cal yr BP.

Magnetic Susceptibility

Magnetic susceptibility measures how readily sediments take on a magnetized charge (Thompson et al., 1975). Instruments that measure magnetic susceptibility in sediment analyze charge using concentration and composition of the materials. Variation in the charges found in sediment cores can indicate disturbance such as erosion, volcanism, floods, and fire events.

Increases in Standard Increment (SI) Unit values indicate an increase in unweathered soil materials within a core, signifying heavy erosion (Lowe & Walker, 1997). These unweathered materials are generally higher in accumulation of metal elements, a quality producing spikes or peaks in magnetic susceptibility readings. At the Reader Fen Basin study site, the high level of aquatic and peat-forming vegetation present increases the rate at which many metals are leached through the soil, encouraging strong signals in magnetics to be interpreted as the result of rapid and sizable influxes of sediment to the site (Pennington et al., 1972).

To determine soil erosion history for the study site, magnetic susceptibility was completed using a Bartington MS2C Core Logging Sensor and measured in SI units. Prior to halving the core for archival preservation and subsampling, the entire core was run through the Bartington sensor in 1-cm increments. This method provides the relative values for changes in susceptibility, not the absolute values (Osleger et al., 2008). The output graph was used to interpret potential fire and flooding events at the study location.

To accommodate the exaggerated sedimentation resulting from a flood event (0.46-0.54) and the subsequent corrected core master depth, standard increment unit readings and sediment depth were amended. Samples obtained from the original depths 0.47-0.54 m were averaged and removed. The average depth for the six removed samples replaced original sample value for original depth 0.47 m. Core master depths for 0.48-2.07 m were also adjusted to reflect the removed samples.

The core taken from Reader Fen Basin (RF10C2) shows a general trend of increasing magnetics with the exception of a large peak found at approximately 2000 cal yr BP, and several smaller peaks at roughly 1000 and 4100 cal yr BP (Figure 8).

Charcoal Analysis

The composite core was sampled in contiguous one-cubic centimeter increments for evaluating charcoal abundance through time (number of particles cm^2 yr^{-1}). Five milliliters of 10% potassium hydroxide were added to the samples and the samples were then soaked in a hot water bath for approximately twenty minutes. The samples were then sieved through a 125-micrometer mesh screen and counted using a dissecting microscope at 40x magnification.

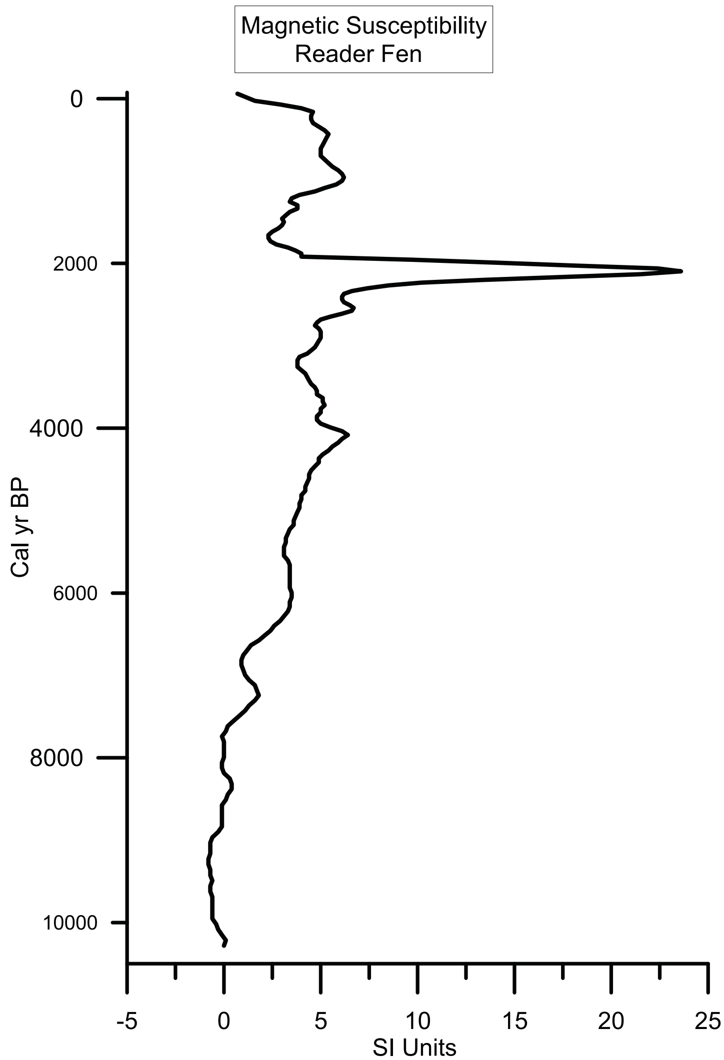

Figure 8: Magnetic Susceptibility for Reader Fen, Uinta Mountains. A high magnitude peak in magnetic signal occurs at 2000 cal yr BP. Two smaller peaks occur at 4100 and 1000 cal yr BP.

Charcoal fragments were tallied from 125 micrometers and larger. Counts were correlated with age of individual samples to determine fire frequency, fire return intervals, and magnitude of individual fire episodes. Occurrence of fire disturbance will be discussed in terms of abrupt responses to the vegetation as well as the long-term patterns of dominant vegetation communities.

CharAnalysis software (Higuera et al., 2009) was used to statistically determine peak occurrence for use with local fire history reconstruction. Charcoal concentrations were interpolated at 47-year intervals. CharAnalysis outputs displayed a background signal –representing regional fire activity and local fire events, shown as peak magnitude (particles/cm^2/event). The background signal was determined using a 1000-year smoother, robust to outliers. Peak magnitudes for fire events are determined by CharAnalysis based on fire size, severity, and proximity (Higuera et al., 2009), reflected through particle accumulation. The fire return interval (FRI) is found by summing the total number of fires within a moving 1000-year period; the FRI is defined as the number of years between each fire event. Charcoal particle counts and sediment depth were amended to accommodate the corrected core master depth. Samples obtained from the original depths 0.47-0.54 m were averaged and removed. The average depth for the six removed samples replaced original sample value for original depth 0.47 m. Core master depths for 0.48-2.07 m were also adjusted to reflect the removed samples.

Pollen Analysis

Sediment samples, 1.0 cubic cm in volume, were processed for fossil pollen and counted using the standard palynological method (Faegri et al., 1989), with the following modifications made to address the high silica content of the sediment. The samples were soaked overnight in a solution of sodium hexmetaphosphate and distilled water to disaggregate the sediments and minimize the shredding of pollen during processing. An additional 60-minute hydrofluoric acid treatment was also preformed due to the high concentration of silicates present in the samples. *Lycopodium* was added as the tracer species.

The samples were treated with safranin stain and preserved in silicon oil. Pollen grains from the processed samples were mounted on slides and counted using light microscopy at 500X magnification. A minimum of 300 *Lycopidium* spores or 300 pollen grains were counted per sample.

Pollen was identified to the lowest taxonomic rank possible using reference slides from the Garrett Herbarium, Kapp et al. (2000), and Erdtman (1952). Pollen accumulation rates (number of pollen grains/taxa/unit of time), or PAR, were calculated and used to determine relative abundance of species through time for the study site. Pollen data were summarized using the software program *Tilia* (Grimm, 1997) and presented as both influx data (grains/cm^2/year) and concentration data (grains/cm^3) (Figures 9-10).

Sediment deposition occurring between 0.46-0.54 m was considered an instantaneous deposit as a result of a massive flood event. To accommodate the

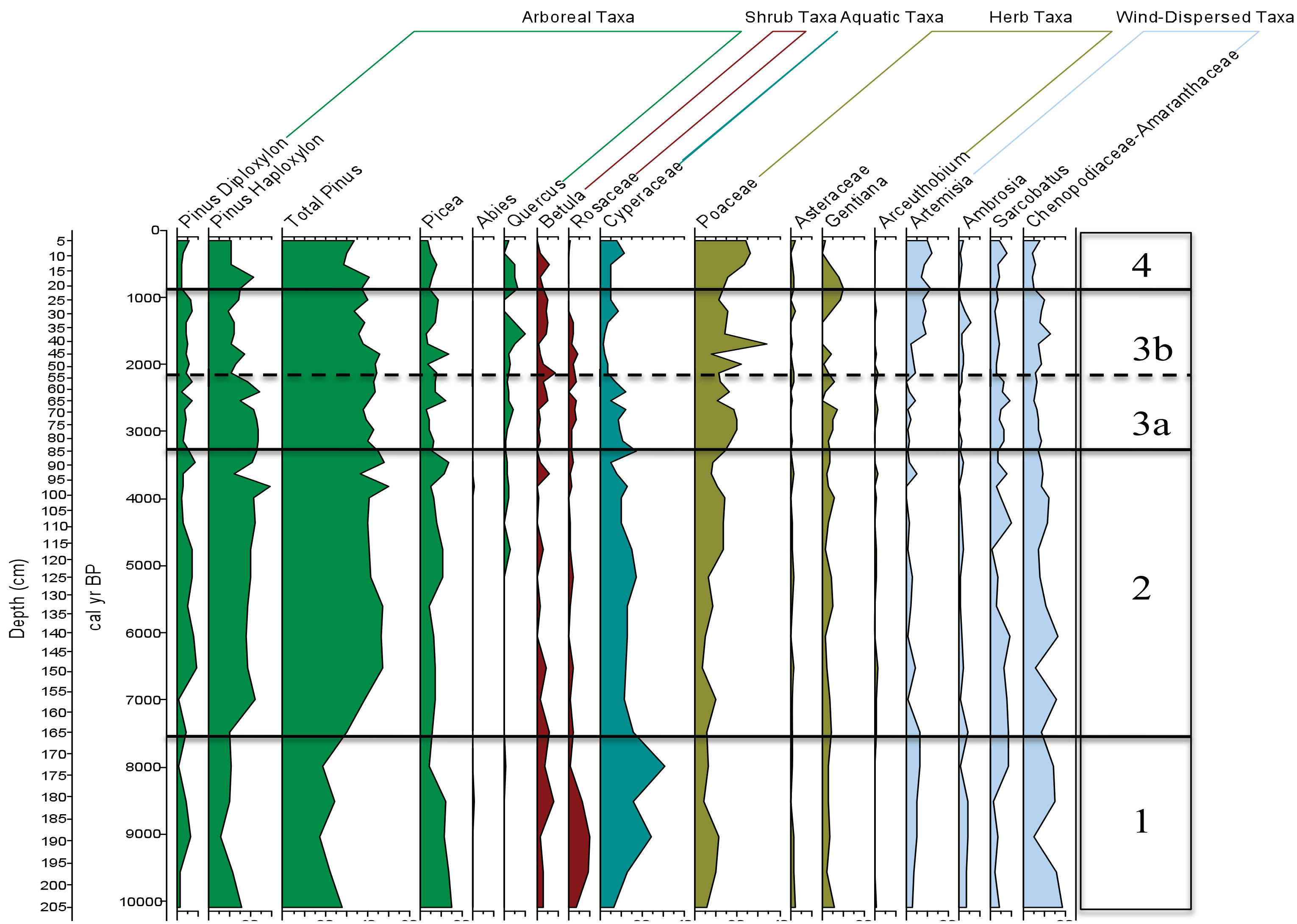

Figure 9: Reader Fen Pollen Percentages.

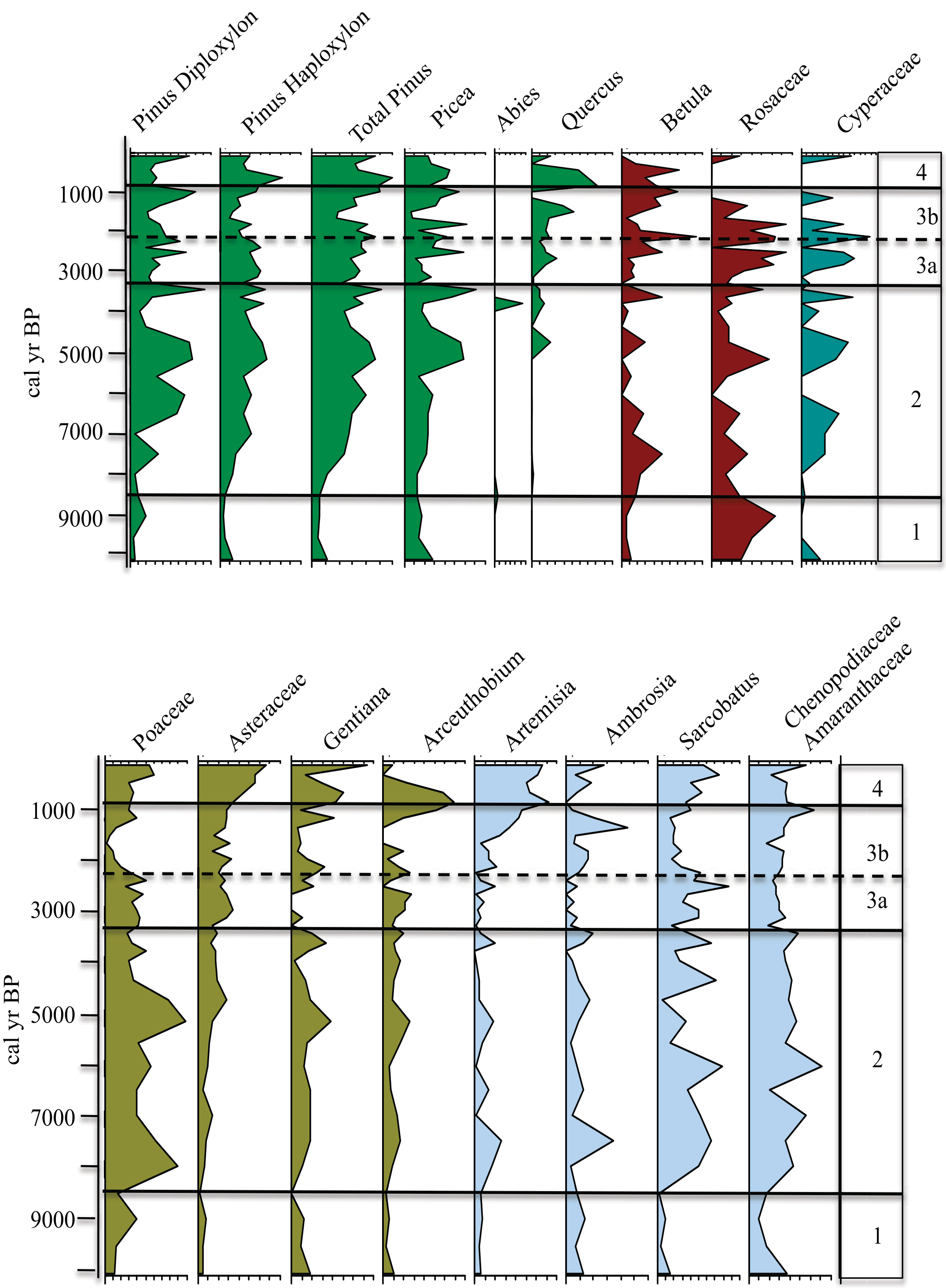

Figure 10: Reader Fen Pollen Influx.

anomalous sedimentation rate, pollen grain counts and sediment depth for this horizon were amended. Pollen samples 49 and 53 -taken from within the intensified horizon- were averaged, applied to sample 49 to represent an undisturbed depth, and removed from the analysis.

Zones were selected based on species abundance and significant change of indicator species described by studies of Shaw and Long (2007) and Fall (1997). To justify zone selection, constrained cluster analysis was run as part of the *Tilia* software package program analysis of the pollen diagram.

A total of nineteen pollen types were identified and sixteen were used to construct the summary pollen diagram. Dominating much of the record are *Pinus*, *Picea*, *Betula*, Cyperaceae, *Gentiana,* and Poaceae.

Leidy Peak Pollen Re-analysis for "A Pollen Study of Holocene Peat and Lake Sediments, Leidy Peak Area, Uinta Mountains, Utah" (Carrara et al., 1985)

In the Carrara et al. (1985) original paper, pollen diagrams for percentage were plotted on a depth scale. To permit comparisons of vegetation change at the Leidy Peak site, Reader Fen Basin, and other known paleoclimate records, a new age model was created by calibrating the original radiocarbon ages, generating a new age-depth model, and interpolating the new ages for the Leidy Peak pollen samples. The new age model was created using four radiocarbon dates specified by the original publication. The dates were calibrated using *Calib 6.0.1* online program (Stuiver & PJ Reimer, 2010), returning date ranges of 544-2135 cal BP, 3260-4294 cal BP, 4237-5323 cal BP, and 6532-7569 cal

BP. *Grapher* software was used to plot calibrated dates to reflect the younger date paired with the lower depth of a sample, while the older date was paired with the upper depth of that same sample. A third-order polynomial was selected based on the consistent probability of the best-fit line residing within the age range. The equation of this line was used to interpolate ages for the remaining corresponding depths.

Grapher software was used to digitize the original pollen diagrams plotted as pollen percentage by depth. Trace taxa were removed from the new diagram dataset. The data obtained were combined with the age model to create new pollen diagrams (Figure 11) with *Tilia* software programs.

Reader Fen Basin zones, identified by using constrained cluster analysis (Grimm, 1997), were used as the framework for discussing the Leidy Peak (Carrara et al., 1985) pollen data. Reader Fen Basin zones discussed below include RF1 (10,250-8500 cal yr BP), RF2 (8500-3200 cal yr BP), RF3a (3200-2100 cal yr BP), RF3b (2100-900 cal yr BP), and RF4 (900 cal yr BP-present).

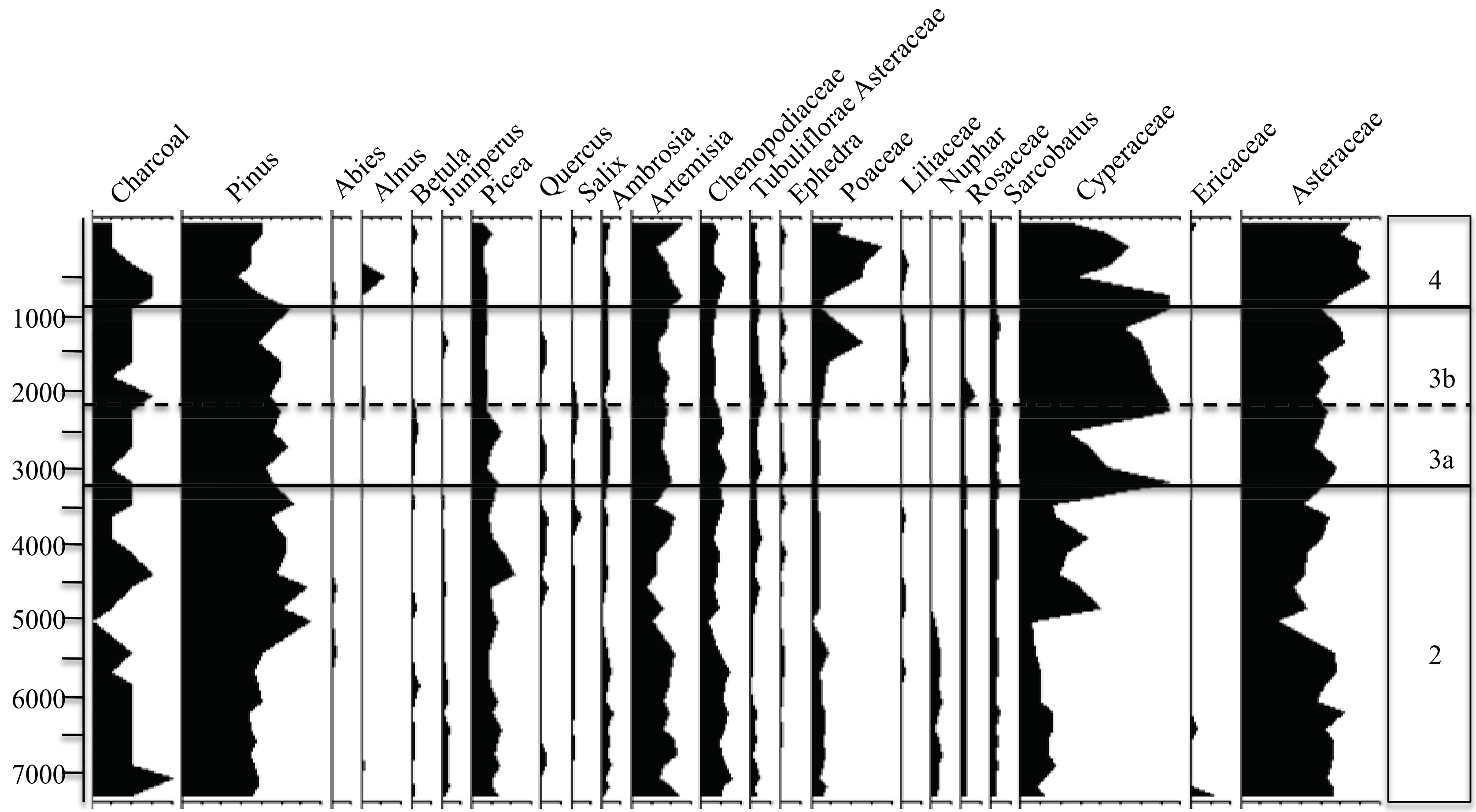

Figure 11: Leidy Peak Pollen Percentages.

CHAPTER FOUR

RESULTS

Lithology

The RF10C2 core is composed largely of sandy silt or silty clay layers, with two 1-3 cm-wide bands of clean, medium sand attributed to paleoflood events. The layer of clean, medium sand, occurring at 0.46-0.54 m and 1.33-1.34 m, are indicative of paleoflood events resulting from a high-energy depositional environment. The high-energy depositional environment at the Reader Fen Basin was likely the result of increased volumes of spring snowmelt. Peat fibers were present throughout the length of the core, excluding the clean, medium sand bands. Peat became the dominant component of the core as depth increased, beginning at approximately 1.8 m and continuing to the end of the core. The silty clay layer found from 1.03-1.88 m indicates a steady, low-energy depositional environment. The presence of intermittent sedge fibers within the layer imply the environment was possibly too warm for peat formation and accumulation but wet meadow species, such as sedge, were still present. The silty sand layers occurring from approximately 0.04-0.43 m indicate that depositional energy has increased slightly from lower in the core, but not with the same magnitude of a paleoflood event.

Magnetic Susceptibility

The core taken from Reader Fen Basin (RF10C2) shows a relatively steady level of magnetic charge through the length of the core with the exception of a massive peak found at approximately 2000 cal yr BP, and several smaller peaks at roughly 1000 and 4100 cal yr BP (Figure 8). As seen in the lithology, the massive peak coincides with the believed paleoflood event, as the increased charge can likely be attributed to the increased depositional energy.

Charcoal

The charcoal-based fire history reconstruction from Reader Fen Basin (3205 m elevation) suggests fires occurred on average every 468 years during the last 10,250 years. This 468-year fire return interval (FRI) was determined using CharAnalysis to deconstruct charcoal count data using a moving 1000-year window (Higuera et al., 2009). CharAnalysis detected 30 peak charcoal episodes throughout the entirety of the record (Figure 12). These episodes ranged in magnitude from 0.22-90.67 particles/cm^2/peak and generally correspond with instances of vegetation shifts and flood events.

Peak analysis determined high-frequency charcoal episodes using a locally defined threshold value and a Gaussian-mixture model for noise distribution. When a charcoal value exceeds the background noise, a peak or episode is detected. Fire events with peak magnitude values greater than 20.00 particles/cm^2/yr were designated as significant fire events. There were ten events of this threshold magnitude occurring in the record at 6800, 6380, 6000, 5630, 3370, 3140, 2340, 1870, 1499, 80 cal yr BP. The

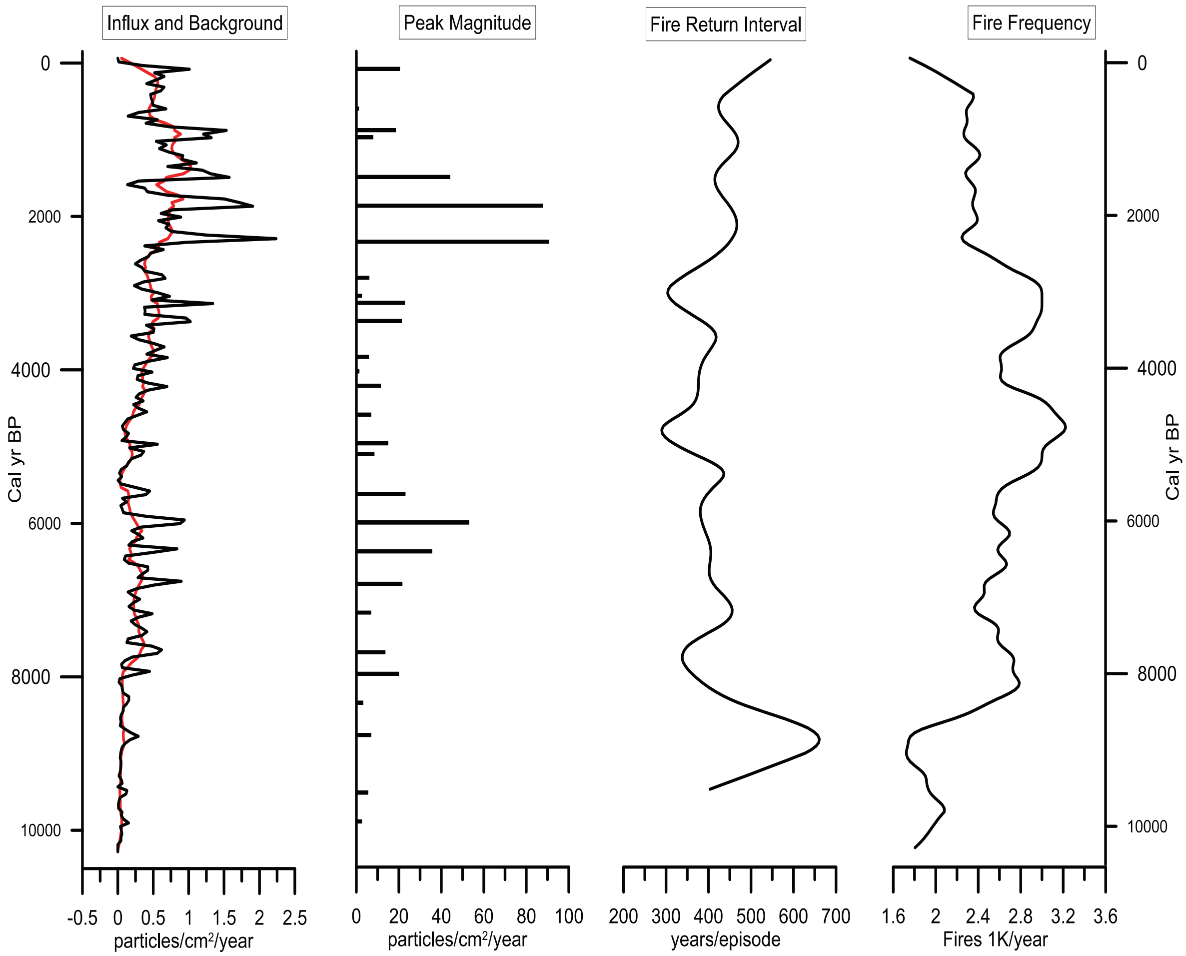

Figure 12: Reader Fen Fire History. The fire history was generated by decomposing the charcoal time series into two components: a peaks component and a background component in CharAnalysis. Charcoal concentrations were interpolated at 47-year intervals. Peak magnitudes for fire events are determined based on fire size, severity, and proximity (Higuera et al., 2009), reflected though particle accumulation. The fire return interval (FRI) is found by summing the total number of fires within a moving 1000-year period; the FRI is defined as the number of years between each fire event, ~468 years.

largest of these severe fire events took place at approximately 1870 and 2340 cal yr BP. Fires events with a lesser peak magnitude but occurring in rapid succession can have a similar influence on vegetative communities by preventing reestablishment of some species and promoting others. Periods where increased fire frequency took place include 3040-3840, 7700-8350, and 4970-5110 cal yr BP.

<u>RF1 (10,250-8500 cal yr BP)</u>

High percentages are found of *Picea* (14%), Cyperaceae (13%), with evidence of *Pinus* (23%) beginning to colonize. Lower elevation sagebrush steppe taxa, including Chenopodiaceae-Amaranthaceae (15%), *Artemisia* (3%), *Ambrosia* (3%) and *Sarcobatus* (3%) are also present.

Total pollen accumulation rate (PAR) for RF1 averaged 1,601 grains/cm^2/yr. The dominant subalpine forest taxa in RF1 are *Pinus* (325 grains/cm^2/yr) with high accumulation of *Picea* (184 grains/cm^2/yr), but near absence of *Abies* (1 grains/cm^2/yr). Rosaceae (101 grains/cm^2/yr) and *Betula* (53 grains/cm^2/yr) are low. Cyperaceae (204 grains/cm^2/yr) dominates the herbaceous taxa and has the highest influx for the wet meadow species; other herbaceous meadow and alpine taxa (Poaceae: 106 grains/cm^2/yr, Asteraceae: 24 grains/cm^2/yr, and *Gentiana*: 55 grains/cm^2/yr) are present but low compared to the rest of the record. Low-elevation, wind-dispersed steppe communities (Chenopodiaceae-Amaranthacea: 197 grains/cm^2/yr, *Sarcobatus*: 40 grains/cm^2/yr, *Artemisia*: 55 grains/cm^2/yr, *Ambrosia*: 53 grains/cm^2/yr) are present and totaled an average of 344 grains/cm^2/yr.

Charcoal results during RF1 suggest fire activity was minimal with no significant fire episodes detected. Average charcoal accumulation rate for the zone was 0.06 particles/cm^2/yr.

RF2 (8500-3200 cal yr BP)

Pinus percentage continues to rise (40%) while *Picea* percentages decrease (8%). Rosaceae decreases from RF1 percentages (7% to 2%). Aquatic species of Cyperaceae (14%) remain the dominant wet meadow pollen type. Alpine meadow pollen types *Gentiana* (3.5%) and Asteraceae (~1%) begin to increase, but remain low.

Total PAR for RF2 averaged 4776 grains/cm^2/yr. PAR values for *Pinus* (1,586 grains/cm^2/yr) and *Picea* (311 grains/cm^2/yr) increased from RF1, while *Abies* (2 grains/cm^2/yr) is present at low amounts. Rosaceae (55 grains/cm^2/yr) and *Betula* (84 grains/cm^2/yr) continue to be present and the first arrival of *Quercus* (25 grains/cm^2/yr) is detected during RF2. Cyperaceae (515 grains/cm^2/yr) continues to dominate the open wet meadow taxa, while Poaceae (340 grains/cm^2/yr), Asteraceae (42 grains/cm^2/yr), and *Gentiana* (130 grains/cm^2/yr) increased.

Five of the ten fire episodes identified with significant peak magnitudes (>20 particles cm^2/yr) occurred during RF2 at 6802, 6379, 6003, 5627, and 3371 cal yr BP. Each of these severe fire events had a peak magnitude value of 20.00 or greater. Periods of lesser magnitude fire events occurring in close succession took place during 8353-7695, 5110-4969, and 3841-3042 cal yr BP. The most recent of these periods of frequent, low magnitude fire events spans RF2 into RF3a. Charcoal accumulation rates averaged 0.3 particles/cm^2/yr for RF2.

RF3a (3200-2100 cal yr BP)

High percentages of *Pinus* (41%) combined with low percentages of *Picea* (6%) characterize RF3a. Percentages of riparian and aquatic types, including *Betula* (3.5%), Rosaceae (2.5%), Poaceae (15%), and Cyperaceae (8%) continue to be present throughout the zone.

Total PAR for RF3a averaged 5254 grains/cm^2/yr. *Pinus* PAR (1724 grains/cm^2/yr) dominated as *Picea* (274 grains/cm^2/yr) decreased slightly. PAR values for riparian and shrub communities of Rosaceae, *Betula*, and *Quercus* increased by 55% to 299 grains/cm^2/yr. Poaceae also increased during RF3a (671 grains/cm^2/yr) and exceeded Cyperaceae (390 grains/cm^2/yr). Alpine meadow pollen types in the Asteraceae and *Gentiana* increased to total 187 grains/cm^2/yr. Low-elevation, wind-dispersed steppe pollen remained present, totaling 622 grains/cm^2/yr.

RF3 was broken into two subzones, RF3a and RF3b. Two significant fire events occurred at 3140 and 2340 cal yr BP. The large magnitude (90.67 particles/cm^2/yr) fire episode at 2340 cal yr BP was the highest magnitude event detected in the RF10C2 record. Charcoal accumulation rates averaged 0.65 particles/cm^2/yr for RF3a.

RF3b (2100-900 cal yr BP)

Pollen percentages for *Pinus* (40%) remain high, while *Picea* (8%) remains low. Pollen percentages for Poaceae (17%) continued to increase as Cyperaceae (4%) decreased. Asteraceae (<1%) and *Gentiana* (3.5%) pollen continue to be present at low percentages. *Betula* (4%) and Rosaceae (1.5%) show a slight increase in percentages from RF3a.

PAR for RF3b averaged 5227 grains/cm^2/yr. *Pinus* (1775 grains/cm^2/yr) and *Picea* (309 grains/cm^2/yr) increased slightly from RF3a. Fen and riparian shrub indicators Poaceae (646 grains/cm^2/yr), Rosaceae (69 grains/cm^2/yr), *Betula* (204 grains/cm^2/yr), and *Quercus* (140 grains/cm^2/yr) continue to increase in influx. Cyperaceae (187 grains/cm^2/yr) remains prevalent but continues to decrease compared to Poaceae influx.

Two significant fire episodes were detected during RF3b, occurring at 1870 and 1490 cal yr BP. The fire episodes at approximately 1870 cal yr BP had the second largest peak magnitude value (87.57) detected in the RF10C2 record. Average charcoal accumulation rate for the zone was 0.91 particles/cm^2/yr.

RF4 (900 cal yr BP-Present)

Pollen percentages of *Pinus* (33%) continued to be the dominant arboreal taxa, with *Picea* (5.5%) also present in lower abundance. Poaceae (22%) remained dominant over Cyperaceae (7%), which decreased significantly since first establishment in the record around 10,250 cal yr BP. Asteraceae (2%) and *Gentiana* (3%) remain present, while *Quercus* (3%), Rosaceae (<1%), and *Betula* (2%) are present but show decreasing abundance toward the present. Sagebrush steppe pollen indicators, including Chenopodiaceae-Amaranthaceae (6%), *Sarcobatus* (4%), *Artemisia* (9%), and *Ambrosia* (1%) remain present throughout the recent part of the record.

Total PAR for RF4 averaged 7391 grains/cm^2/yr. Total *Pinus* (2147 grains/cm^2/yr) increased dramatically compared to the rest of the record and *Picea* (340 grains/cm^2/yr) maintained a presence through RF4. Poaceae pollen (1384 grains/cm^2/yr) increased significantly in RF4, while aquatic indicator, Cyperaceae (450 grains/cm^2/yr) increased only slightly, as did riparian shrub and high moisture taxa Rosaceae (17 grains/cm^2/yr), *Betula* (147 grains/cm^2/yr), and *Quercus* (188 grains/cm^2/yr). Alpine meadow taxa Asteraceae (103 grains/cm^2/yr) and *Gentiana* (226 grains/cm^2/yr) pollen also increased in abundance. Steppe vegetation indicators increased slightly in RF4 to total PAR value of 1307 grains/cm^2/yr.

One fire episode was identified as having a significant peak magnitude during RF4, occurring at approximately 80 cal yr BP, or AD 1870. Charcoal accumulation rates averaged 0.53 particles/cm^2/yr for RF4.

CHAPTER FIVE

FIRE, VEGETATION, AND CLIMATE HISTORY

The results from the Reader Fen Basin study provide insight into the long-term vegetation, fire, and climate history of the eastern Uinta Mountains. The following discussion is organized chronologically into zones of significant vegetation change at Reader Fen Basin during the Holocene. Studies from Leidy Peak (Carrara et al., 1985), Snowbird bog (Madsen & Currey, 1979), Blue Lake Marsh (Louderback & Rhode, 2009), and Bear Lake (Jimenez-Moreno et al., 2007) are compared to the results from Reader Fen Basin.

Early Holocene (10,250-8500 cal yr BP)

The earliest part of the Reader Fen Basin record is characterized by a high abundance of *Picea engelmannii* and low abundance of other arboreal species (*Pinus, Abies, Quercus*), indicative of a community that Fall (1997) terms a spruce steppe. During the early Holocene, prior to 9000 cal yr BP, several alpine herbaceous species, including Rosaceae, Poaceae, *Gentiana*, and Asteraceae increased in open areas, indicating the initial development of fen complex following the recession of Uinta Mountain glaciers. Pyrophilic species, including members of the Poaceae family and *Pinus contorta* were relatively low when compared to the remainder of the record, while wetland species, including Cyperaceae were abundant. The presence of Cyperaceae and other mesophytic taxa, such as Rosaceae and *Betula*, combined with the dominance of *Picea engelmannii* indicate cooler- and possibly wetter-than-present conditions, potentially related to the proximity of Reader Fen Basin to retreating glaciers in the high elevation of the Uinta Mountains (Munroe, 2003). The absence of pyrophilic taxa and relatively low charcoal accumulation rates suggest fire activity was low during the initial postglacial development of Reader Fen Basin. At approximately 8500 cal yr BP, charcoal accumulation increased at the same time as the replacement of *Picea* by *Pinus contorta* and Poaceae, suggesting fire became a more important disturbance agent.

The Reader Fen Basin vegetation record during the early Holocene indicates a major shift in system dominance from grasses and alpine herbaceous species, including Rosaceae, Poaceae, *Gentiana*, and Asteraceae. Arboreal species, including *Picea* and *Pinus*, began arriving around 9000 cal yr BP. This shift represents an emigration of grass and herbaceous communities into the watershed and reduction of spruce-pine forests. This change in the composition of flora occurs as climate began warming.

Analysis of the fire regimes at Reader Fen Basin study area during the early Holocene suggests infrequent fires of medium magnitude occurred at 9900, 9530, and 8780 cal yr BP. Several smaller magnitude, higher frequency fire episodes also occurred at this time, although the average fire return interval of 468 years suggests fire was relatively uncommon during the early history of Reader Fen Basin. As the fen and adjacent forest continued to develop into the early Holocene, fire became increasingly prevalent and was likely linked to the developing understory steppe that provided greater available fuel (Agee & Skinner, 2005).

The high abundance of *Picea engelmannii* during the early Holocene at Reader Fen Basin combined with evidence of Chenopodiaceae-Amaranthaceae, *Sarcobatus*, *Ambrosia*, and *Artemisa*, all lower-elevation, xerophytic taxa today, suggests the high elevations of the Uinta Mountains were a more open, steppe-like environment at this time during the early Holocene. Previous studies from Snowbird bog (Madsen & Currey, 1979) and Blue Lake Marsh (Louderback & Rhode, 2009) show patterns of increasing xerophytic taxa, similar to Reader Fen Basin. Snowbird bog shows a dominance of deciduous forest, including Alnus with *Picea* and *Pinus* also present in moderate abundance (Madsen & Currey, 1979). Following the arrival of warmer- and wetter-than-present conditions generated by the monsoon arrival at approximately 8800 cal yr BP, Madsen and Currey (1979) suggest a major expansion of conifer forest, including *Pinus* and *Picea*. Similarly, at Blue Lake Marsh, evidence of a shift from cool and wet conditions, reflected in the dominance of wetland taxa, to warm, dry conditions is seen at the same time as the monsoon arrives to Snowbird bog (Louderback & Rhode, 2009). The increasing abundance of Chenopodiaceae-Amaranthaceae and *Juniperus* and decreasing abundance of *Artemisia* and *Pinus* at Blue Lake Marsh beginning approximately 8800 cal yr BP supports this shift (Louderback & Rhode, 2009). However, at Blue Lake, the climate shift is likely attributed to the increased subtropical high-pressure zone blocking moisture to Western Utah.

The regional climate of the Uinta Mountains and surrounding regions between 11,000 and 8000 cal yr BP has been characterized as having a stronger-than present northeastern Pacific subtropical high-pressure system (Bartlein et al., 1998) that would have impacted large-scale circulation during the early Holocene. Bartlein et al. (1998)

suggest increased subsidence from expanded subtropical high pressure would have blocked moisture moving into the region and resulted in warmer temperatures, lower-than-present precipitation, and greater soil moisture deficits. Early Holocene Northern Hemisphere summer insolation maximum between 11,000 and 8000 cal yr BP likely affected regional climates by contributing to greater heating and rapid snowmelt in the late spring and summer months and would have promoted longer growing seasons in high-elevation settings.

Middle Holocene (8500-3200 cal yr BP)

During the middle Holocene, from 8500-3200 cal yr BP, vegetation and lithologic records for Reader Fen Basin suggest the arrival of the monsoon signal in the Uinta Mountains. The monsoon brought onshore flow of warm, moist air from the Gulf of Mexico and Gulf of California, which created warmer- and wetter-than present conditions (Whitlock & Bartlein, 1993). This energized climate system generated a much wetter environment, evident in the expanding subalpine forest of mixed forest of *Pinus contorta* and *Picea engelmannii* with open wet meadows, dominated by members of the Cyperaceae.

Pollen percentage data (Figure 9), which convey the general trends and displacements of species relative to one another, does not support the idea of an expanding subalpine forest, suggesting a decrease in *Picea engelmannii* presence. However, pollen accumulation rate data (Figure 10), which convey the actual abundance of each species present in the landscape over time, shows a general increase in both *Pinus* and *Picea* presence. While climatic conditions encouraged the expansion of subalpine forest during the middle Holocene, the expected expansion of *Picea engelmannii* was dampened by the increased presence of fire activity. This fire activity likely encouraged the establishment of *Pinus contorta* as the dominant arboreal species, which likely explains the apparent decrease in *Picea* in pollen percentage data.

Several smaller magnitude fire episodes occurred in the record between 7700-8350 cal yr BP. The arrival of *Pinus contorta* following these events suggests fire may have been localized to the Reader Lakes watershed. However, the continued presence of *Picea* in conjunction with consistently low abundance of members of Poaceae and *Betula* in the subalpine forest population suggests disturbance from fire was sufficient in affecting understory taxa but did not cause the local extirpation of *Picea* forest.

The middle Holocene is also characterized at Reader Fen Basin by an increase in wind-dispersed taxa, including Chenopodiaceae-Amaranthaceae and *Sarcobatus* likely arriving from communities at lower elevations. The absence of *Abies concolor,* considered a mesic species, for much of the middle Holocene, as well as the low abundance of Poaceae suggests the area was much drier-than-present (Thompson, Anderson, & Bartlein, 1999).

Shrub populations, including Rosaceae, *Betula, Artemisia,* and *Ambrosia*, begin decreasing after 7000 cal yr BP and continue until the late Holocene transition. Modern vegetation in Reader Fen Basin includes Rosaceae and *Betula* as the dominant alpine shrubs on the raised, hummocky strings found within the fen system. During the early Holocene, both *Artemisia* and *Ambrosia* were likely wind-dispersed from the lower elevations, within the Uinta Basin, and may not have been present within the fen.

The decrease in shrub vegetation may result from an increasing density of the surrounding forest rather than a lowering of the water table, as there is evidence for an increasingly wet climate resulting from the early Holocene warming trend. Wetter climates are suggested as northern hemisphere summer insolation increased and the southwestern monsoons expanded into more northerly regions (Poore et al., 2005).

A general warming trend is indicated during the middle Holocene by the appearance of *Quercus* by approximately 5000 cal yr BP. Modern *Quercus* communities are seen along the southern base of the Uinta Mountains. Generally high levels of insolation (Figure 13) could encourage *Quercus* populations to expand upslope into the higher elevations of the range. The appearance of *Quercus* is also seen at approximately 5000 cal yr BP in the Leidy Peak study, suggesting a regional response of vegetation.

A possible flood event detected in the Reader Fen Basin sediments at 5700 cal yr BP may be linked to increased monsoon moisture. A 1-cm-thick band of clean, pink sand in the sediment stratigraphy at ca. 5700 cal yr BP suggests a significant flood event occurred in response to either rapid spring melt and excessive runoff or heavy summer precipitation. Following this flood event during the middle Holocene, fen vegetation shifts from Cyperaceae dominated to Poaceae dominated, as well as, an increase in arboreal species, including *Quercus*, all indicative of increasing moisture and, in the case of *Quercus*, increasing growing season temperature. It is possible that the disturbance caused by the abrupt flood event around 5700 cal yr BP effectively caused an increase in grasses by depositing a thick layer of well-drained sandy sediment in the fen, providing an elevated, well-drained substrate for grass to colonize.

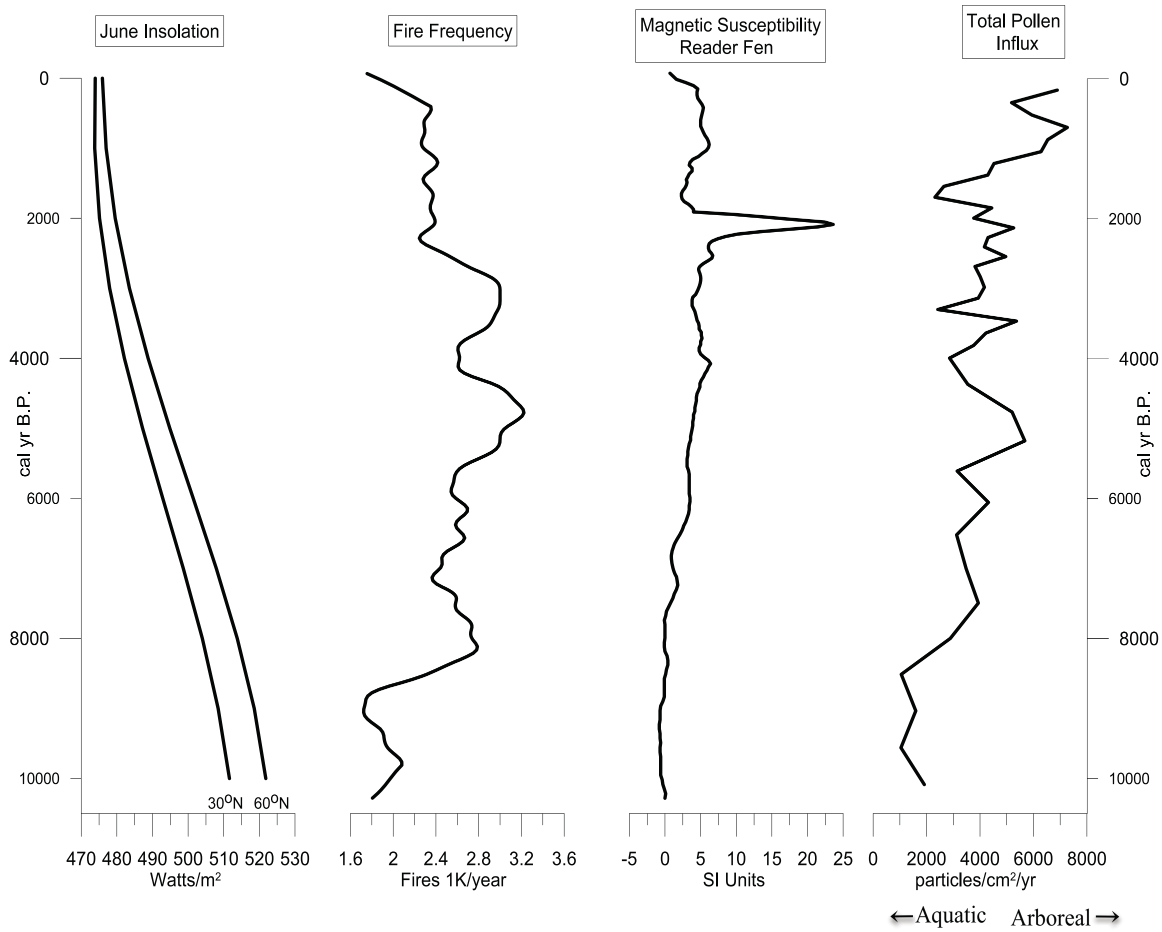

Figure 13: Reader Fen Basin, Uinta Mountains, USA Paleoclimate Summary. June insolation data for 30°N and 60°N collected from Berger and Loutre (1991). The insolation curve represents the changing climate of the northern Hemisphere for the duration of the Reader Fen Basin record. Fire frequency was determined using CharAnalysis (Higuera et al., 2009). The magnetic susceptibility curve of Reader Fen Basin depicts influxes of sedimentation due to flood events. Arboreal taxa for the PAR ratio were designated as *Pinus*, *Picea*, *Abies*, and *Quercus*. Aquatic taxa for the PAR ratio were designated as Cyperaceae.

The disappearance of peat accumulation in the core stratigraphy supports the middle Holocene warming trend. It is possible that while Cyperaceae was present at Reader Fen Basin during the Middle Holocene, evident in pollen data and plant macrofossils, conditions were not conducive for peat production. For peat accumulation to occur, peat production must be greater than decomposition, an objective that is less likely in warmer-than-present conditions (Mitsch & Gosselink, 1993).

The charcoal record (Figure 12) shows large-magnitude fire episodes at approximately 6800 and 6380 cal yr BP, signifying local fire episodes, followed by several frequent episodes between 3840-3040 cal yr BP. This increase in fire frequency is also apparent in the vegetation response, which shows decreasing *Picea* followed by increasing *Sarcobatus* and Chenopodiaceae-Amaranthaceae (Figures 9-11).

A peak in fire frequency occurs at 5300 cal yr BP, corresponding with the first arrival of *Quercus* at Reader Fen Basin. The rapid recovery of *Quercus* following fire episodes is likely linked to the successful colonization. Fire activity decreased by 4700 cal yr BP, allowing a shift from pyrophilic species, including *P. contorta*, to less fire-tolerant species, including *Picea*. The large-magnitude fire episode, which occurred at 6000 cal yr BP (Figure 12), was likely responsible for the rapid decrease followed by gradual recovery of understory taxa, including *Gentiana*, Asteraceae, Rosaceae, Poaceae, and Cyperaceae. Following this disturbance, *Pinus* began to re-establish in the record, while *Picea* continues to retreat, likely due to the increased wet conditions of the area combined with several high-magnitude, frequently occurring fire episodes (Dirr, 1998; Thompson et al., 1999). Increased fire activity may also be linked to increased erosion, as suggested by a peak in magnetic susceptibility 4100 cal yr BP.

As fire activity increased during the middle Holocene at Reader Fen Basin, *Picea* forests gradually gave way by approximately 4500 cal yr BP to increasing abundance of pyrophilic species, including; *Pinus contorta,* Poaceae*,* Asteraceae, and *Gentiana*. The presence of Cyperaceae, Poaceae, and *Pinus* suggests a long-term warming trend at the fen. This warming trend is also evident in both local and regional studies surrounding Reader Fen Basin.

Locally, the Leidy Peak pollen record suggests a decrease in a predominately winter wet climate, evident by the desiccation of the small lake found at the study site and the disappearance of *Nuphar* (Carrara et al., 1985). Following the desiccation of the lake, *Quercus*, Cyperaceae, *Juniperus*, and *Betula* began to dominate the record, beginning approximately 5000 cal yr BP.

Madsen and Currey (1979) describe an increase in conifer forest taxa (primarily *Pinus flexilis*) at Snowbird bog, suggesting warmer- and wetter-than-present conditions. These conditions are similar to those that arrived during the end of the late Holocene and are likely attributed to the arrival of an invigorated monsoon circulation.

Approximately 8000-6500 cal yr BP increased warmer- and drier-than-present conditions are seen at Blue Lake Marsh (Louderback & Rhode, 2009), evident in the desiccation of wetland taxa, creating a shift to dominance of grasses and xerophilic shrub communities, including Poaceae, *Allenrolfea*, and Chenopodiaceae-Amaranthaceae. Louderback and Rhode (2009) suggest that grass meadows and playa species persisted until 2800 cal yr BP. Between 8000-6500 cal yr BP, climate warming is indicated at Blue Lake Marsh as *Pinus edulis* becomes established, likely a result of increased middle

Holocene temperatures (Louderback & Rhode, 2009). Fire likely played a role in the expansion of these woodlands, but was not investigated in the Blue Lake Marsh study.

Regional climate of the Intermountain West between 8500 and 3200 cal yr BP continued to be generally warmer-than-present, but was punctuated with centennial-scale periods of cooler-than-present temperatures. This middle Holocene climate variability was temporally asynchronous in terms of the regional onset and duration (Fall, 1997; Bartlein et al., 1998; Munroe, 2003). Bartlein et al. (1998) suggest the presence of a stronger-than-present southwestern monsoon signal between 11,000 and 6000 cal yr BP resulting from increasing onshore flow during summer and increasing sea-level pressure creating greater-than-present precipitation. The increase in precipitation and cloudiness likely decreased the warming effects of greater-than-present insolation in the region; however, this was unlikely to create a net decrease in annual temperature (Bartlein et al., 1998). In the Uinta Mountains and surrounding regions, the strengthened summer monsoon signal became influential by ca. 7500 cal yr BP, as evident by shifts in vegetation at Reader Fen Basin and adjacent study sites (Poore et al., 2005).

Late Holocene (3200-900 cal yr BP)

Climate during the late Holocene, 3200-900 cal yr BP, showed similar conditions to that of the middle Holocene with evidence of warm, wet conditions resulting from the invigorated monsoon signal in the region. Vegetation during the late Holocene shows *Gentiana*, *Quercus*, and *Betula* steadily increasing, consistent with wetter- and warmer-than-present conditions. Also during the late Holocene, high abundance of *Artemisia* and *Sarcobatus*, lower-elevation species found in the Great Basin area indicate a slight cooling and drying trend relative to the middle Holocene. Poaceae displaces Cyperaceae as the dominant meadow taxa beginning at approximately 3200 cal yr BP. The increase of taxa requiring greater annual moisture, including Rosaceae and *Betula* by 3200 cal yr BP, and subsequent decline in alpine meadow species Asteraceae and *Gentiana* suggests the fen may have transitioned to support higher water tables and an increase in wetland vegetation.

At approximately 2000 cal yr BP, from 46-54 cm in the composite core stratigraphy, a thick band of clean, pink, quartzite sand entered Reader Fen Basin, forming a distinct layer surrounded by high levels of silty sand (Figure 7). The distinctiveness of this sand layer and its coarse quartz composition suggests the material was rapidly transported into the system, possibly in response to an abrupt flood event. Bioturbation and natural sedimentation allow the sand to be incorporated into the younger layers, dominated by the characteristic silt and clay found throughout the core. This flood event, the most significant of the record, supports the idea of increased effective moisture during the last two millennia.

Fire activity after 3200 cal yr BP is considerably lower than during the middle Holocene; however, the two largest peak magnitude fire episodes occurred at approximately 2340 and 1870 cal yr BP. The high magnitude fire episode at 2340 cal yr BP follows a major flood disturbance during the late Holocene at approximately 2000 cal yr BP, suggesting that the increased level of ground water resulted in increased abundance of understory taxa, including Poaceae and *Salix*, which led to short-term increases in total biomass. However, the general lack of fire activity during this time may be attributed to a longer-term trend of increasing effective moisture, as an increasingly wet fen became enclosed by *Pinus* and riparian shrub communities (Thompson et al., 1999; Shaw & Long, 2007).

Regionally, the late Holocene shows evidence of centennial-scale warm and cool periods. Reader Fen Basin is characterized by a dominance of subalpine forest communities of *Pinus* and *Picea* but shows evidence of an expanding open, wet meadow. This late Holocene period of greater effective moisture contributed to the continued increase in moisture tolerant communities of *Pinus*, Rosaceae, *Betula*, and Cyperaceae.

The Leidy Peak vegetation record shows a similar response to the warming trend as Cyperaceae species increase as the lake gradually desiccated beginning at approximately 5000 cal yr BP and continuing into the late Holocene (Cararra et al., 1985). *Pinus* begins to dominate the montane forests around Leidy Peak as *Picea* and *Abies* decrease in abundance. During the last millennia, the Leidy Peak record indicates the establishment of fen vegetation as long-term climatic cooling began approximately 2000 cal yr BP (Carrara et al., 1985). During the last millennia, Cyperaceae and Poaceae dominate the local vegetation at the site.

At Snowbird bog, warmer- and wetter-than-present conditions continue, though conditions are slightly cooler and slightly drier than those of the middle Holocene. Warm, dry conditions began to develop at Snowbird bog approximately 2000 cal yr BP. This change is evident with the increasing deciduous taxa and *Artemisa* and the decreasing conifer forest as modern climate conditions became established at Snowbird bog (Madsen & Currey, 1979).

At Blue Lake Marsh, climatic cooling is evident from 2700-1500 cal yr B.P (Louderback & Rhode, 2009) as *Artemisia* increased and Chenopodiaceae-

Amaranthaceae decreased. This cooler period is bracketed by warmer periods at Blue Lake Marsh, characterized by increasing amounts of *Juniperus* and Chenopodiaceae-Amaranthaceae and decreasing abundance of *Pinus* and (Louderback & Rhode, 2009). Beginning approximately 2000 cal yr BP, Louderback and Rhode (2009) suggest Fremont horticulturalists colonized the Blue Lake Marsh region as climate gradually warmed and growing seasons lengthened.

Paleoclimate reconstructions for northeastern Utah between 3200 and 900 cal yr BP suggest an attenuation of the Holocene climate optimum and the arrival of cooler-than-present conditions (Carrara et al., 1985; Bartlein et al., 1998; Anderson et al., 1999; Munroe, 2003). In the Pacific Ocean, the intensified El Nino Southern Oscillation (ENSO) between 3000 and 1000 cal yr BP likely created increased variability and contributed to cooler-than-present conditions in the western United States. However, the response within the Uinta Mountains to the intensification of ENSO and hemispheric climate cooling during the late Holocene is controversial, with geomorphic evidence suggesting the surrounding region experienced a slight warming trend at this time (Munroe, 2003).

The Reader Fen Basin vegetation record shows evidence of a possible response to the onset of the Medieval Warming Period (MWP; 1150-550 cal yr BP) at the end of the early Holocene and into the last millennia. Abundance of *Pinus*, *Gentiana*, and *Quercus* increase rapidly beginning at approximately 1100 cal yr BP, while riparian communities of Cyperaceae and Rosaceae abundance decreases. The shifts in taxa abundance indicate warmer and drier conditions, consistent with the presence of the MWP. A sharp decrease in *Pinus contorta* pollen accumulation rate is shown at 900 cal yr BP; however, it is hypothesized that this decline is related to increased beetle (*Dendroctonus* sp.) disturbance resulting from beetle population growth following favorable conditions created by the MWP.

Last Millennia (900 cal yr BP-present)

Modern vegetation for Reader Fen Basin was established during the last millennia and is characterized as a sedge- and grass- dominated fen surrounded by subalpine forest of *Pinus contorta* and *Picea engelmannii*. During the last 900 cal yr BP to present, climate continued to become cooler and drier than conditions seen in the middle Holocene, but generally remained warmer- and wetter-than-present. The subalpine forest of *Pinus contorta* and *Picea engelmannii* continued to be the dominant vegetation community until approximately 500 cal yr BP when evidence of fen communities began to reestablish. Herbaceous taxa, including members of Asteraceae and *Gentiana*, peak during the last millennia, along with Cyperaceae, Poaceae, *Quercus,* and *Betula*. This may be attributed to the long-term cooling trend and the low incidence of fire during this time. Approximately this same time, core lithology shows a resurgence of peat accumulation.

Evidence of the climate anomaly of the Little Ice Age (LIA; 550-150 BP) may be present in the Reader Fen Basin vegetation record. Increased abundance of cold-tolerant, low-growing herbs or shrubs Poaceae, and Rosaceae, visible in the pollen accumulation rates, beginning at approximately 500 cal yr BP may be the indicate intensified cooling.

A decrease in biomass burning during the last millennia may have limited pyrophilic species, including *Pinus contorta*, which requires fire for successful reproduction (Dirr, 1998). An increase in wind dispersed pollen from the Great Basin area, including Chenopodiaceae-Amaranthaceae, *Sarcobatus*, and *Artemisia* suggests an expansion of these lower-elevation species during the last millennia.

After 700 cal yr BP, FRI increase slightly; however, peak magnitudes become less severe. The long-term trend in vegetation at Reader Fen Basin suggests that flood events increased in frequency. The increased abundance of *Betula* and *Quercus* in the modern vegetation implies fire episodes during the last 700 cal yr BP promoted a vegetation community that can quickly resprout after a fire (Hayward, 1952; Shaw & Long, 2007). The decreasing levels of background charcoal found during the last millennia (Figure 12) reinforce the interpretation of a reduction in fire episodes during the last few centuries.

While the record remains dominated by subalpine forest, Reader Fen Basin undergoes a major shift in vegetation communities returning to a peat-producing fen. This shift is likely the result of slightly cooler, wet conditions following the decreased energy of the monsoon signal in the Uinta Mountains anomalous cool periods (LIA), and the stabilization of modern climate. Local modern vegetation found at Leidy Peak (Carrara et al., 1985) shows evidence of climatic cooling as bog vegetation (Cyperaceae, Poaceae) continue to overtake conifer forest communities (*Pinus, Picea*). Snowbird bog vegetation shows evidence of increasing conifer forest in the late Holocene, primarily *Picea*, *Abies*, and *Psudotsuga* (Madsen & Currey, 1979). Regionally, vegetation at Blue Lake Marsh (Louderback & Rhode, 2009) shows evidence of slight warming as the record transitions out of the cool periods, which occurred at 2700 and 1500 cal yr BP during the middle to late Holocene.

Data collected by the Ashley National Forest Service during the late millennia, spanning approximately 50 cal yr BP to present, show little evidence of fire activity in the eastern Uinta Mountains. The reconstruction from this study indicates that fire is present at Reader Fen Basin occurring at an average frequency of 470 years. The absence of fire events in the Ashley National Forest Service data can likely be attributed to the scale from which data have been collected and the variability of fire events (Morris, 2010).

CHAPTER SIX

CONCLUSIONS

This study explored the hypothesis that climate is the primary driver of ecosystem dynamics in the eastern Uinta Mountains, Utah, USA. Quantifying the frequency of disturbance and subsequent influence on high-elevation plant communities, this study explored the linkages among changes in floristic composition, natural disturbance, and climate variability. Data from Reader Fen Basin show three major shifts in vegetation composition documented during the last 11,000 years include: 1) the displacement of grass and alpine herbaceous communities as arboreal species colonized during the early Holocene, between 10,250 and 9000 cal yr BP; 2) the displacement of *Picea engelmannii* as *Pinus contorta* forests expanded into the watershed during the middle Holocene, beginning at 9000 cal yr BP when fire had a prominent role in the ecosystem; and 3) the displacement of members of Cyperaceae family as grasses began to dominate the fen during the late Holocene, beginning at 3200 cal yr BP. These three major shifts in vegetation composition are largely the result of changing climate and fire frequency.

Based on the data from this reconstruction, the earliest portion of the Reader Fen Basin vegetation history suggests a cool, wet regional climate that supported *Picea-Artemisia* steppe community that colonized recently deglaciated terrain. Vegetation communities at Reader Fen Basin shifted to increasing abundance of Cyperaceae, Poaceae, and *Pinus contorta*, beginning around 8800 cal yr BP, implying both regional warming and an increase in fire activity in the area. The immigration of pyrophilic species suggests an extirpation of fire-sensitive species (e.g., *Picea*) out of the Reader Fen Basin watershed. Regional studies conducted at Snowbird bog (Madsen & Currey, 1979) and Blue Lake Marsh (Louderback & Rhode, 2009) reflected cool, wet climate conditions with vegetation communities dominated by alpine communities at Snowbird bog between 13,000 and 8000 cal yr BP and wetland taxa, including *Carex*, *Salix*, and *Schoenoplectus*, at Blue Lake Marsh between 11,900 and 8800 cal yr BP. A warming trend began regionally at approximately 8800 cal yr BP, evident in the increasing dominance of *Picea engelmannii* conifer forests at Snowbird bog (Madsen & Currey, 1979), as *Picea* migrated upslope in response. Climatic warming was also suggested from the Blue Lake Marsh study as Chenopodiaceae-Amaranthaceae and *Juniperus* vegetation communities increased while *Artemisia* and *Pinus* decreased (Louderback & Rhode, 2009). Beginning at approximately 3200 cal yr BP, a subalpine forest (*Pinus*, *Picea*) was well established in the area of the Reader Fen Basin, suggesting generally warm conditions punctuated by periods of abrupt flooding, which contribute to establishing areas of open, wet meadow (Cyperaceae, Poaceae, Rosaceae, and *Betula*).

Periods of abrupt flooding punctuate the Reader Fen Basin record, most evident during the late Holocene. Vegetation history at Leidy Peak reflects a similar pattern of Holocene climate variability of cool, wet conditions from 7500 to 5000 cal yr BP, followed by distinct warming trend from 5000 cal yr BP until approximately 2000 cal yr BP when bog vegetation became established as cooler conditions impacted the local vegetation. The overall climate interpretation from regional studies by Madsen and

Currey (1979) and Louderback and Rhode (2009) is consistent with the Reader Fen Basin interpretation; however, the onset of the initial warming, around 8800 cal yr BP at Snowbird bog and Blue Lake Marsh precedes that of Reader Fen Basin and Leidy Peak. The increased sensitivity to Holocene climate variability of Snowbird bog and Blue Lake Marsh can likely be attributed to the site's position along ecotonal gradients.

Characteristic mid-Holocene climate variability is present both regionally and locally, however, more apparent in lower elevation sites. For example, at Snowbird bog (Madsen & Currey, 1979), *Picea engelmannii* colonizes the area during the warming trend beginning 8000 cal yr BP, followed by an increase in wetter-than-present conditions between 6000 and 5000 cal yr BP, evident with the further displacement of *Pinus flexilis* with *Picea engelmannii*, and concludes with cooler-than-present conditions beginning 5000 cal yr BP. At Blue Lake Marsh (Louderback & Rhode, 2009), the Holocene warming trend, which begins 8800 cal yr BP, is interrupted by cooler-than-present intervals between 4400-3400 and 2700-1500 cal yr BP

During the middle Holocene, vegetation at Reader Fen Basin begins to reflect the warm, dry trend present at both Snowbird bog (Madsen & Currey, 1979) and Blue Lake Marsh (Louderback & Rhode, 2009), which began at the end of the early Holocene. Desiccation of wetland communities at both Leidy Peak (Carrara et al., 1985) and Blue Lake Marsh (Louderback & Rhode, 2009) occur as the warming trend continued. This is evident in the disappearance of lake taxa (*Nuphar*) and arrival of *Quercus* pollen at Leidy Peak (Carrara et al., 1985) and the shift to xerophilic shrub communities, including Poaceae, *Allenrolfea*, and Chenopodiaceae-Amaranthaceae, at Blue Lake Marsh (Louderback & Rhode, 2009). Vegetation indicating warm, dry climate continues at

Snowbird bog (Madsen & Currey, 1979) with increasing presence of *Pinus flexilis* until approximately 6800 cal yr BP when a slight increase in *Picea engelmannii* implies a return to cool, wet conditions. This period of cool, wet conditions, suggested by the retreating conifer forest, persists until 3900 cal yr BP when warm, dry vegetation communities regain dominance.

Regional and local vegetation during the late Holocene is driven by rapid fluctuations in warm and cool climate periods. The Leidy Peak (Carrara et al., 1985) vegetation record implies maximum warming conditions, shown in the increase of *Pinus* and *Abies*, until approximately 2000 cal yr BP when bog vegetation dominants the record, suggesting the onset of a cooler period. Similarly, vegetation at Blue Lake Marsh (Louderback and Rhode, 2009) continues to exhibit Holocene warming; however, a period of cooling begins at approximately 2700 cal yr BP, supported by increasing *Artemisia* presence, and remains until 1500 cal yr BP when *Juniperus* and Chenopodiaceae-Amaranthaceae regain dominance. Snowbird bog (Madsen & Currey, 1979) shifts from wet conditions seen previously in middle Holocene to cooler and slightly drier conditions as precipitation stabilizes to the Holocene average.

The conclusions that can be drawn from the regional analysis include:

- High elevation montane sites, such as Reader Fen Basin and Leidy Peak (Carrara et al., 1985), record a period of cool, wet conditions in the early Holocene following deglaciation of the Uinta Mountains, followed by warm, wet periods generated by the onset of monsoon conditions arriving from the Gulf of Mexico during the middle to late Holocene, and a return to slightly cooler conditions as the records move into modern conditions.

- The Little Cottonwood Canyon site (Madsen & Currey, 1979) exhibits similar vegetation response to changing climate conditions as the Uinta Mountains, showing a dominance of deciduous forest in the cooler, drier conditions of the early Holocene, with an expansion of conifer forests after the arrival of the warmer, wetter conditions during the middle to late Holocene. A retreat of conifer forest follows the onset of cooler, drier conditions in the last millennia.
- While the Blue Lake Site (Louderback & Rhode, 2009) is not governed by the same atmospheric patterns, due to location, elevation, and topography, the record does show a related response to regional climate change present in the montane sites. Blue Lake demonstrates a shift from cool, wet conditions supporting wetland taxa in the early Holocene to warm, dry conditions dominated by playa and grassland meadow beginning ~8800 cal yr BP as moisture availability in the Intermountain West shifts.

Reconstruction of the vegetation, fire, and climate history for the Reader Fen Basin in the eastern Uinta Mountains demonstrates a dynamic environment being shaped by climate factors, including fire and extreme runoff events. It is clear from the data analyzed that paleoflood events, while present, were not sustained for a duration or magnitude great enough to produce long-term shifts in vegetation communities.

While Ashley National Forest Service records for the past 100 years show minimal evidence of fire activity in the eastern Uinta Mountains, data from the Reader Fen Basin indicate that fire is not only present, occurring at an average frequency of 470 years, it is a driver in shaping conifer and meadow composition. The fire reconstruction from the Reader Fen Basin study shows several large to medium magnitude fire events occurring during the past 11 ka years. These fires show evidence of altering the composition of dominant forest species. Management implications for the forest service, including more extensive fire reconstructions for the Uinta Mountain range, are necessary to determine if past fire episodes are an analog for future events.

Regional fire regimes for sites in south-central Utah compiled by Morris (2010) reflect considerable variability in fire return interval and magnitude when compared to the Reader Fen Basin reconstruction. Fire disturbance in the Intermountain West is controlled largely by climate drivers including El Nino/Southern Oscillation and the North American Monsoon.

However, while data from the Reader Fen Basin reflect the presence and importance of fire episodes, it is clear that climate is the primary driver of vegetation composition, producing long-term shifts throughout the Intermountain West. The Reader Fen Basin vegetation, climate, and fire history reconstruction explores the floristic history of the site and identifies the processes responsible for influencing the long-term stability of vegetation communities. Data from this study determine that climate is the dominant driver of ecosystem dynamics in the eastern Uinta Mountains, while fire is a secondary driver of long-term vegetation shifts.

Future Work

To improve our understanding of factors influencing the ecosystem dynamics of the Uinta Mountains, additional disturbance regimes must be examined. At the Reader Fen Basin site, evidence of possible beetle disturbance (*Dendroctonus* sp.) is present occurring at 900-500 cal yr BP. To explore the relative importance of beetle disturbance, future analysis should explore techniques for quantifying past beetle outbreaks in the watershed and the response of these types of disturbances to Holocene vegetation dynamics.

To create a comprehensive understanding of factors influencing immigration, emigration, and extinction of populations in Uinta Mountains, additional study locations should be compiled. In order to track the appearance or extirpation of a species throughout its geographic range, additional study locations at various elevations with past pollen records documenting species range expansions and contractions would provide key insights into the persistence of species through time. Examining changes in floristic composition in relation to periods of past climate change will also allow the dominant drivers of ecosystem change in the Uinta Mountains to be evaluated.

Table 3: Regional Vegetation Summary.

	Reader Fen Basin		Leidy Peak		Snowbird Bog		Blue Lake		Bear Lake	
	Climate	Vegetation	Climate	Vegetation	Climate	Vegetation	Climate	Vegetation	Climate	Vegetation
Early Holocene 10,250-8500 cal yr BP	Cool, Wet (winter wet resulting from increased cloudiness)	Spruce Steppe	Record N/A	Record N/A	Warm,Wet (drier than onset of monsoon) Warm,Wet 8800 cal yr BP (arrival of monsoon)	Deciduous Forest, *Pinus*, *Picea* present Conifer Forest Dominant	Cool, Wet Warm, Dry beginning 8800 cal yr BP	Wetland Increase *Juniperus*, Chenopodiaceae -Amaranthaceae	Record N/A	Record N/A
Mid-Holocene 8500-3200 cal yr BP	Warm, Wet (arrival of monsoon, less winter wet, increased summer wet)	Pyrophilic taxa increase, Conifer Forest, Arrival of *Quercus*	Warm, Wet (arrival of monsoon, less winter wet, increased summer wet)	Cyperaceae, *Betula* dominant, Local extinction of *Nuphar* 5000 cal yr BP	Warm,Wet	Conifer Forest Dominant	Warm, Dry	Playa taxa, Grassland Meadow, establishment of *Pinus edulis*	Record N/A	Record N/A
Late Holocene 3200-900 cal yr BP	Warm, Wet, abrupt flood events	Subalpine Forest, Alpine Meadow	Warm, Wet Slight Cooling beginning 2000 cal yr BP	*Pinus* Forest Cyperaceae and Poaceae Increase	Warm, Dry ~2000 cal yr BP	Deciduous Forest, Steppe Vegetation, Decreasing Conifer Forest	Warm, Dry Cooling 2700-1500 cal yr BP	*Juniperus*, Chenopodiaceae -Amaranthaceae Increase *Pinus*, *Artemisia*	Record N/A	Record N/A
Last Millennia 900 cal yr BP - Present	Warm, Wet (cooler and drier than onset of monsoon)	Subalpine Forest, Fen, and Alpine Meadow	Cool, Wet	Bog Vegetation	Warm, Wet (cooler, drier than onset of monsoon)	*Picea*, *Abies*, *Pseudotsuga* Conifer Forest (Modern Vegetation)	Warm, periods of Cool, Wet	*Juniperus*, Chenopodiaceae -Amaranthaceae Wetland taxa (cool, wet)	Warm, Dry	*Pinus edulis* and *Juniperus*, *Populus* Forest, *Artemisia* Steppe

Studies included are Reader Fen Basin, Leidy Peak (Carrara et al., 1985), Snowbird bog (Madsen & Currey, 1979), Blue Lake Marsh (Louderback & Rhode, 2009), and Bear Lake (Jimenez-Moreno et al., 2007).

APPENDIX

Field Notes

July 7, 2010 Reader Fen

Core 2: Lower Part of the Middle Meadow -1m West of C1

Present: Rick Ford, Mitch Power, Hannah Wilson, Sean Meyer, Rebecca Koll, Sam Kennedy, Mike Devito, Oliver Squire and Katrina Moser

Conditions: Sunny with a slight wind 60-65*

Drive 1: -Drive Depth 32cm -Recovered 29cm –Total Depth Reached 32cm

Description of D1

Length	**Description**
0-3cm	Root Mat
3-8cm	Light Brown Sand
8-27cm	Medium Brown Silty Sand
27-29cm	Light Brown Sand

Drive 2: -Drive Depth 23cm –Recovered 24cm (1cm of Slump) -Total Depth Reached 55cm

Description of D2

Length	**Description**
0-17cm	Silty Sand
17-21cm	Medium Brown Silty Clay
21-24cm	Silty Sand

Drive 3: -Started 6cm above the last core -Drive Depth 51cm –Recovered 55cm –Total Depth Reached 1.06cm

Description of D3

Length	**Description**
0-5cm	Slough
5-17cm	Sandy Silt, Medium Brown in Color
17-36cm	Silty Clay
36-37cm	Sandy Silt, Light Brown in Color
37-55cm	Silty Clay, Medium Brown in Color

Drive 4: -Drive Depth 67cm –Recovered 57cm (10cm of Compression) –Total Depth Reached 1.73m

Description of D4

Length	**Description**
0-5cm	Brown Silty Clay with an Inner Core Consisting of Red/Rusty Sand
5-6cm	Dark Brown Layer – Possibly Charcoal
6-12cm	Silty Clay
12-13cm	Dark Brown Charcoal Layer
13-30cm	Silty Clay
30-31cm	Light Brown Sand not Rusty
31-39cm	Silty Clay
39-40cm	Dark Brown Layer – Possibly Charcoal
40-50cm	Silty Clay
50-57cm	Medium Brown Silty Clay

Drive 5: -Drive Depth 67cm –Recovered 46cm (Peat caused the core to compact by 20cm) –Total Depth Reached 2.40m

Description of D5

Length	**Description**
0-27cm	Medium Brown Silty Clay
27-46cm	Peat Layer

Drive 6: -Drive Depth 3cm –Recovered 3cm (Hit Rock) –Total Depth Reached 2.43cm

Description of D6

Length	**Description**
0-3cm	A Little Peat– Mostly Sand

Raw Data

Charcoal Counts

Depth (cm)	Charcoal Count (particles/cc)
1	0
2	7
3	53
4	21
5	29
6	30
7	14

8	24
9	35
10	20
11	21
12	21
13	22
14	22
15	32
16	10
17	6
18	25
19	17
20	19
21	79
22	36
23	78
24	32
25	16
26	36
27	21
28	32
29	39
30	33
31	55
32	26
33	32
34	60
35	50
36	66
37	13
38	6
39	4
40	25
41	12
42	27
43	60
44	47
45	83
46	64
47	24
48	24
49	18
50	40
51	15
52	28
53	20
54	25
55	20
56	48

57	36
58	91
59	43
60	10
61	15
62	24
63	19
64	11
65	17
66	11
67	10
68	7
69	15
70	12
71	24
72	21
73	28
74	9
75	8
76	13
77	13
78	30
79	28
80	17
81	61
82	16
83	13
84	19
85	13
86	51
87	41
88	15
89	21
90	25
91	10
92	4
93	26
94	17
95	39
96	13
97	21
98	36
99	14
100	10
101	10
102	25
103	11
104	13
105	21

106	35
107	18
108	14
109	12
110	19
111	8
112	17
113	22
114	8
115	6
116	4
117	2
118	8
119	7
120	1
121	29
122	8
123	21
124	16
125	7
126	9
127	3
128	1
129	3
130	0
131	3
132	20
133	30
134	3
135	7
136	2
137	4
138	5
139	54
140	50
141	17
142	9
143	24
144	12
145	9
146	58
147	7
148	5
149	9
150	29
151	22
152	17
153	54
154	23

155	8
156	13
157	20
158	8
159	14
160	31
161	10
162	15
163	21
164	28
165	9
166	8
167	41
168	35
169	13
170	3
171	4
172	30
173	2
174	1
175	4
176	4
177	10
178	10
179	5
180	5
181	2
182	3
183	2
184	11
185	19
186	8
187	4
188	3
189	2
190	3
191	3
192	2
193	1
194	5
195	0
196	11
197	2
198	1
199	0
200	4
201	3
202	10
203	2

204	4
205	3
206	15
207	17

Pollen Count

depth (cm)	age (Cal yr BP)	Lycopodium	Pinus Diploxylon	Pinus Haploxylon	Total Pinus	Abies
1	-60	26	14	30	98	0
5	161.7479991	25	16	32	101	0
9	340.8119926	29	9	33	93	0
13	518.8602297	26	7	36	96	0
17	695.3785845	22	8	74	144	0
21	869.8529309	21	6	45	114	0
25	1041.769143	22	20	44	124	0
29	1210.613095	30	22	28	103	0
33	1375.87066	30	12	34	111	0
37	1537.027713	52	12	36	111	0
41	1693.570127	59	15	32	115	0
45	1844.983777	34	14	57	153	0
49	1990.75548	43	19	45	155.5	0
53	2131.055602	29	14	34	146	0
57	2267.942997	39	26	66	154	0
61	2403.799906	36	7	76	139	0
65	2541.008573	36	26	55	153	0
69	2681.929812	39	11	67	118	0
73	2827.953913	37	14	69	121	0
77	2979.124484	42	12	86	156	0
81	3135.38594	37	9	70	122	0
85	3296.682696	62	17	71	141	0
89	3462.959164	30	29	70	162	0
93	3634.15976	39	11	41	126	0
97	3810.228898	36	8	83	144	2
101	3991.110991	60	7	78	149	0
109	4367.091703	42	9	70	128	0
117	4761.657208	31	25	70	144	0
125	5174.362821	28	24	71	146	0
133	5604.763855	46	17	61	156	0
141	6052.415623	31	24	54	143	0
149	6516.864598	48	33	66	167	0
157	6997.037512	38	3	69	123	0
165	7490.845367	36	15	33	105	0
173	7996.105013	44	3	34	60	0
181	8510.633269	114	13	29	74	1
189	9032.10541	39	10	9	28	0
197	9557.72697	73	3	22	44	0
205	10084.69314	66	5	53	93	0

depth (cm)	age (Cal yr BP)	Betula	Picea	Artemisia	Ambrosia	Cyperaceae	Poaceae
1	-60	0	12	29	5	24	75
5	161.7479991	0	10	29	6	24	72
9	340.8119926	5	16	36	2	36	81
13	518.8602297	20	25	28	5	16	77
17	695.3785845	7	20	26	2	17	55
21	869.8529309	10	12	34	0	15	40
25	1041.769143	17	27	23	1	15	35
29	1210.613095	14	24	29	7	26	48
33	1375.87066	16	21	23	15	10	43
37	1537.027713	15	8	28	4	8	44
41	1693.570127	4	10	7	4	4	103
45	1844.983777	7	46	10	6	8	26
49	1990.75548	11	13	13	7.5	12	77
53	2131.055602	29	26	13	4	12	36
57	2267.942997	11	26	1	4	27	43
61	2403.799906	14	22	4	0	39	51
65	2541.008573	19	45	15	3	20	40
69	2681.929812	3	9	1	0	38	57
73	2827.953913	6	14	7	2	26	60
77	2979.124484	5	15	2	0	35	73
81	3135.38594	6	20	5	3	33	52
85	3296.682696	0	17	2	2	54	44
89	3462.959164	7	45	4	6	17	28
93	3634.15976	21	38	16	5	27	26
97	3810.228898	0	15	0	0	38	31
101	3991.110991	5	22	1	3	37	52
109	4367.091703	0	24	4	4	32	43
117	4761.657208	10	38	3	6	53	48
125	5174.362821	0	37	11	3	62	22
133	5604.763855	6	15	8	2	43	27
141	6052.415623	0	20	1	3	41	16
149	6516.864598	15	26	15	7	44	11
157	6997.037512	6	22	1	2	36	32
165	7490.845367	22	20	23	15	54	18
173	7996.105013	13	14	19	2	98	19
181	8510.633269	25	37	15	12	47	12
189	9032.10541	3	18	8	7	39	18
197	9557.72697	6	27	7	7	26	19
205	10084.69314	11	50	9	11	22	18

depth (cm)	age (Cal yr BP)	Sarcobatus	Chenopodiaceae-Amaranthaceae	Arceuthobium	Asteraceae
1	-60	13	19	0	6
5	161.7479991	12	24	2	8
9	340.8119926	22	13	0	2
13	518.8602297	11	21	0	4
17	695.3785845	13	17	0	6
21	869.8529309	8	17	0	5
25	1041.769143	10	31	0	1
29	1210.613095	5	27	2	7
33	1375.87066	7	23	0	1
37	1537.027713	11	40	0	2
41	1693.570127	13	22	0	3
45	1844.983777	11	26	3	1
49	1990.75548	8.5	30.5	1	3.5
53	2131.055602	9	20	4	5
57	2267.942997	22	24	3	5
61	2403.799906	17	18	0	2
65	2541.008573	33	20	3	4
69	2681.929812	15	21	4	0
73	2827.953913	12	23	3	0
77	2979.124484	22	26	1	0
81	3135.38594	19	27	0	2
85	3296.682696	11	23	1	0
89	3462.959164	12	30	0	3
93	3634.15976	27	33	4	7
97	3810.228898	8	26	0	3
101	3991.110991	17	46	2	1
109	4367.091703	32	37	0	3
117	4761.657208	2	26	3	3
125	5174.362821	11	29	2	6
133	5604.763855	8	37	0	4
141	6052.415623	28	51	0	2
149	6516.864598	21	22	4	5
157	6997.037512	24	50	2	4
165	7490.845367	29	31	2	4
173	7996.105013	27	47	0	3
181	8510.633269	4	47	1	0
189	9032.10541	5	9	0	3
197	9557.72697	3	32	0	4
205	10084.69314	14	64	3	8

depth (cm)	age (Cal yr BP)	Rosaceae	Gentiana	Quercus
1	-60	0	6	5
5	161.7479991	3	4	5
9	340.8119926	0	0	0
13	518.8602297	0	13	16
17	695.3785845	0	28	17
21	869.8529309	0	32	19
25	1041.769143	0	26	0
29	1210.613095	0	13	0
33	1375.87066	6	0	13
37	1537.027713	7	0	30
41	1693.570127	4	0	14
45	1844.983777	14	15	7
49	1990.75548	9	4	8.5
53	2131.055602	10	9	7
57	2267.942997	13	22	4
61	2403.799906	0	6	6
65	2541.008573	14	0	7
69	2681.929812	10	22	13
73	2827.953913	12	16	7
77	2979.124484	7	18	4
81	3135.38594	4	9	1
85	3296.682696	5	12	1
89	3462.959164	8	12	3
93	3634.15976	3	9	4
97	3810.228898	4	9	6
101	3991.110991	2	22	6
109	4367.091703	4	10	0
117	4761.657208	3	6	8
125	5174.362821	9	16	0
133	5604.763855	4	18	0
141	6052.415623	0	4	0
149	6516.864598	8	8	0
157	6997.037512	3	12	0
165	7490.845367	8	15	0
173	7996.105013	4	9	1
181	8510.633269	20	9	0
189	9032.10541	16	6	0
197	9557.72697	19	4	0
205	10084.69314	13	19	0

Magnetic Susceptibility

Depth	age	SI Unit
0	-60	0.7
1	27.09269271	1.6
2	71.99575803	2.9
3	116.8835379	4
4	161.7479991	4.6
5	206.5811083	4.5
6	251.3748325	4.5
7	296.1211383	4.6
8	340.8119926	4.9
9	385.4393621	5.2
10	429.9952136	5.4
11	474.4715139	5.3
12	518.8602297	5.2
13	563.153328	5.1
14	607.3427753	5
15	651.4205386	5
16	695.3785845	5
17	739.20888	5.2
18	782.9033916	5.4
19	826.4540864	5.6
20	869.8529309	5.9
21	913.0918921	6.1
22	956.1629366	6.2
23	999.0580313	6.1
24	1041.769143	5.8
25	1084.288238	5.2
26	1126.607284	4.7
27	1168.718247	3.9
28	1210.613095	3.5
29	1252.283793	3.4
30	1293.722308	3.8
31	1334.920609	3.8
32	1375.87066	3.4
33	1416.564429	3.2
34	1456.993883	3
35	1497.150989	3.1
36	1537.027713	3
37	1576.616022	2.8
38	1615.907883	2.5
39	1654.895262	2.3
40	1693.570127	2.3

41	1731.924445	2.4
42	1769.950181	2.7
43	1807.639303	3.3
44	1844.983777	3.7
45	1881.975571	4
46	1918.606651	4
47	1954.868985	9.7
48	1990.75548	14
49	2026.280733	18
50	2061.481022	22.4
51	2096.393571	23.6
52	2131.055602	21.5
53	2165.504338	17.5
54	2199.777001	13.4
55	2233.910813	10.2
56	2267.942997	8.5
57	2301.910776	7.4
58	2335.851372	6.6
59	2369.802008	6.2
60	2403.799906	6.1
61	2437.882289	6.1
62	2472.08638	6.2
63	2506.4494	6.5
64	2541.008573	6.7
65	2575.80112	6.6
66	2610.864265	6.1
67	2646.234437	5.5
68	2681.929812	5
69	2717.950316	4.8
70	2754.29508	4.7
71	2790.963235	4.9
72	2827.953913	5
73	2865.266245	5
74	2902.899364	5
75	2940.8524	4.9
76	2979.124484	4.8
77	3017.714749	4.7
78	3056.622326	4.5
79	3095.846346	4.3
80	3135.38594	3.9
81	3175.240241	3.8
82	3215.40838	3.8
83	3255.889487	3.8
84	3296.682696	4
85	3337.787136	4.2
86	3379.20194	4.3

87	3420.926239	4.4
88	3462.959164	4.5
89	3505.299847	4.7
90	3547.94742	4.8
91	3590.901014	4.8
92	3634.15976	5.1
93	3677.72279	5.1
94	3721.589235	5.2
95	3765.758227	5
96	3810.228898	5
97	3855.000378	4.8
98	3900.071799	4.8
99	3945.442293	5
100	3991.110991	5.5
101	4037.077025	6.1
102	4083.339526	6.4
103	4129.897625	6.1
104	4176.750455	5.9
105	4223.897146	5.6
106	4271.33683	5.4
107	4319.068638	5.1
108	4367.091703	4.9
109	4415.405154	4.9
110	4464.008125	4.7
111	4512.899746	4.5
112	4562.079149	4.4
113	4611.545465	4.4
114	4661.297826	4.3
115	4711.335363	4.2
116	4761.657208	4.2
117	4812.262492	4
118	4863.150347	4
119	4914.319903	3.9
120	4965.770294	3.9
121	5017.500649	3.8
122	5069.510101	3.7
123	5121.797781	3.6
124	5174.362821	3.6
125	5227.204351	3.4
126	5280.321504	3.3
127	5333.713411	3.2
128	5387.379203	3.2
129	5441.318012	3.1
130	5495.528969	3.1
131	5550.011206	3.1
132	5604.763855	3.3

133	5659.786046	3.4
134	5715.076911	3.4
135	5770.635582	3.4
136	5826.46119	3.4
137	5882.552867	3.4
138	5938.909744	3.4
139	5995.530952	3.5
140	6052.415623	3.5
141	6109.562889	3.4
142	6166.971881	3.4
143	6224.641731	3.3
144	6282.571569	3.1
145	6340.760527	2.9
146	6399.207667	2.6
147	6457.910422	2.4
148	6516.864598	2.1
149	6576.065932	1.8
150	6635.51016	1.4
151	6695.193017	1.2
152	6755.110241	1
153	6815.257566	0.9
154	6875.630729	0.9
155	6936.225465	1
156	6997.037512	1.1
157	7058.062605	1.3
158	7119.296479	1.6
159	7180.734872	1.7
160	7242.373519	1.8
161	7304.208156	1.6
162	7366.234519	1.3
163	7428.448344	1.1
164	7490.845367	0.8
165	7553.421325	0.5
166	7616.171953	0.2
167	7679.092987	0.1
168	7742.180163	-0.1
169	7805.429218	0
170	7868.835887	0
171	7932.395907	0
172	7996.105013	0
173	8059.958941	-0.1
174	8123.953428	-0.1
175	8188.08421	0
176	8252.347022	0.3
177	8316.737601	0.4
178	8381.251683	0.4

179	8445.885003	0.2
180	8510.633269	0.1
181	8575.491525	-0.1
182	8640.454152	-0.1
183	8705.515502	-0.1
184	8770.669926	-0.1
185	8835.911777	-0.1
186	8901.235407	-0.3
187	8966.635167	-0.6
188	9032.10541	-0.7
189	9097.640488	-0.7
190	9163.234752	-0.7
191	9228.882555	-0.8
192	9294.578249	-0.8
193	9360.316185	-0.7
194	9426.090716	-0.7
195	9491.896194	-0.6
196	9557.72697	-0.7
197	9623.577396	-0.7
198	9689.441826	-0.6
199	9755.31461	-0.6
200	9821.190232	-0.6
201	9887.065958	-0.6
202	9952.941684	-0.6
203	10018.81741	-0.4
204	10084.69314	-0.3
205	10150.56886	-0.1
206	10216.44459	0.1
207	10282.32031	0

Plant Survey List

Table 4: Plant Survey List.

Family	Genus	Species	Authority	Description	Location
Asteraceae	*Achillea*	*millefolium*	L.	Perennial herb, 20cm tall; corolla cream	Duchesne County: Reader Fen Basin, upper meadow
Asteraceae	*Antennaria*	*microphylla*	Rydb.	Perennial herb, 15-18cm; corolla cream	Duchesne County: Reader Fen Basin, upper meadow
Asteraceae	*Solidago*	*cf. multiradiata*	Aiton	Perennial herb, 10-15 cm tall; corolla yellow. Hairs less pronounced than on typical *S. multiradiata*; possible hybrid with *S. simplex*	Duchesne County: Reader Fen Basin, upper meadow
Crassulaceae	*Rhodiola*	*rhodantha*	(Gray) Jacobsen	Perennial herb, 18-25 cm tall; semi-succulent, corolla red, foliage red to green	Duchesne County: Reader Fen Basin, open meadow
Cyperaceae	*Carex*	*aquatilis*	Wahl.	Perennial sedge, large stands: culms tufted, thick rhizomes. Height: 16-20 cm	Duchesne County: Reader Fen Basin, open, wet meadow
Cyperaceae	*Carex*	*limosa*	L.	Perennial sedge. Height: 18-20cm	Duchesne County: Reader Fen Basin, open, wet meadow
Cyperaceae	*Eriophorum*	*scheuchzeri*	Hoppe	Creeping rhizomes, 25-30 cm; white, tufty stamens	Duchesne County: Reader Fen Basin, open, wet meadow
Cyperaceae	*Trichophorum*	*cespitosum*	(L.) Hartm.	Perennial sedge, large stands: culms tufted, thick rhizomes. Height: 15-25 cm	Duchesne County: Reader Fen Basin, open wet meadow
Gentianaceae	*Gentiana*	*algida*	Pallas	Perennial herb, 15-22 cm tall; corolla white mottled with purple near base and along lobes	Duchesne County: Reader Fen Basin, riparian community
Gentianaceae	*Gentiana*	*calycosa*	Griseb.	Perennial herb, 8-10 cm tall; corollas blue or yellow	Duchesne County: Reader Fen Basin, riparian community

Table 4: Plant Survey List Continued.

Family	Genus	Species	Authority	Description	Location
Poaceae	*Danthonia*	*intermedia*	Vasey	Perennial. Height: 12-20 cm	Duchesne County: Reader Fen Basin, open, wet meadow
Poaceae	*Deschampsia*	*cespitosa*	(L.) Beauv.	Perennial graminoid, 40cm tall	Duchesne County: Reader Fen Basin, open, wet meadow
Primulaceae	*Dodecatheon*	*pulchellum*	(Raf.) Merr.	Perennial herb, 15 cm tall; corolla purple	Duchesne County: Reader Fen Basin, open, wet meadow
Rosaceae	*Potentilla*	*diversifolia*	Lehm.	Perennial herb, 15-20 cm tall; corolla yellow	Duchesne County: Reader Fen Basin, upper meadow
Rosaceae	*Potentilla*	*fruticosa*	L.	Perennial shrub 0.5 m tall; corollas yellow	Duchesne County: Reader Fen Basin, riparian community
Ranunculaceae	*Caltha*	*leptosepala*	DC.	Perennial herb, 10-15 cm tall; corolla cream	Duchesne County: Reader Fen Basin, open, wet meadow
Scrophulariaceae	*Pedicularis*	*groenlandica*	Retz.	Perennial herb, 12-30 cm tall; corollas purple, white corollas also observed but not collected	Duchesne County: Reader Fen Basin, open, wet meadow

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